Final

The Monterey Ecological Staircase: The Nature of Vegetation and Soils on Different Geomorphic Surfaces of the Monterey Peninsula with an Emphasis on Monterey Pine Forest

Submitted by:

Jones & Stokes Associates, Inc.
2600 V Street, Suite 100
Sacramento, CA 95818-1914
Contact: Paul D. Cylinder, Ph.D.
916/737-3000

Submitted to:

Deborah Hillyard and Diane Steeck
California Department of Fish and Game
Natural Heritage Division
1416 Ninth Street
Sacramento, CA 95814-2090

Funded by:

Emergency Drought Relief Project Contract
No. CA HER 112093 and
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INTRODUCTION AND PROJECT OBJECTIVES

The flora of the Monterey Peninsula has been well documented (Howitt and Howell 1964, 1973; Howitt 1972; Matthews 1992). Soils of the peninsula have been mapped by the U.S. Soil Conservation Service (SCS) (Cook 1978). Monterey pine and Monterey pine forest are well studied (Coleman 1905, Scott 1960, Roy 1966, Vogl et al. 1988). The unusual pygmy forests on Huckleberry Hill and near Gibson Creek and the marine terrace deposits on which they occur have been described (Griffin 1972, Holland 1986, Vogl et al. 1988, Stebbins 1993). Recently, the geology of the peninsula has been described and the geologic relationships between geomorphic surfaces elucidated (Dupré 1990). However, the relationships between geomorphic surfaces, soils, and vegetation have not be previously explained for the Monterey Peninsula. This study was conducted to describe the ecological and historical relationships between geomorphic surfaces, soils, and vegetation of the Monterey Peninsula and surrounding areas (Figures 1, 2, and 3). The ecological system at Monterey was found to be remarkably similar to the "ecological staircase" of coastal Mendocino County described 25 years ago by Jenny et al. (1969).

This study was conducted as part of a larger project to prepare an ecological assessment of and conservation strategy for Monterey pine (*Pinus radiata*) and the Monterey pine forest community. The focus of this study was to develop a classification of Monterey pine forest into forest subtypes as the canopy and understory vegetation vary with the different soils found on different geomorphic surfaces. A second objective was to generate a map of the historical extent of the Monterey pine forest that could differentiate between and estimate the historical extent of different subtypes of Monterey pine forest. These endeavors were conducted with great reliance on the excellent geology map produced by Dupré (1990) (Figure 4). The classification of subtypes of Monterey pine forest and the recognition of the relationships between the forest subtypes and geomorphic surfaces are key components in the development of a meaningful forest conservation plan. This information will allow conservation planning efforts to take into account the protection of the full range of variation in this rare natural community, based on accurate estimates of the historical and present extent of forest subtypes.

Geomorphic Surfaces

The study was organized by geomorphic surfaces that support Monterey pine forest or that are important to understanding the limits to the distribution of Monterey pine forest. Vegetation and soils on 17 geomorphic surfaces were described (Figure 4). Geomorphic surfaces were divided into five major types:

- marine terraces,
- intervening slopes between marine terraces,
- dunes,

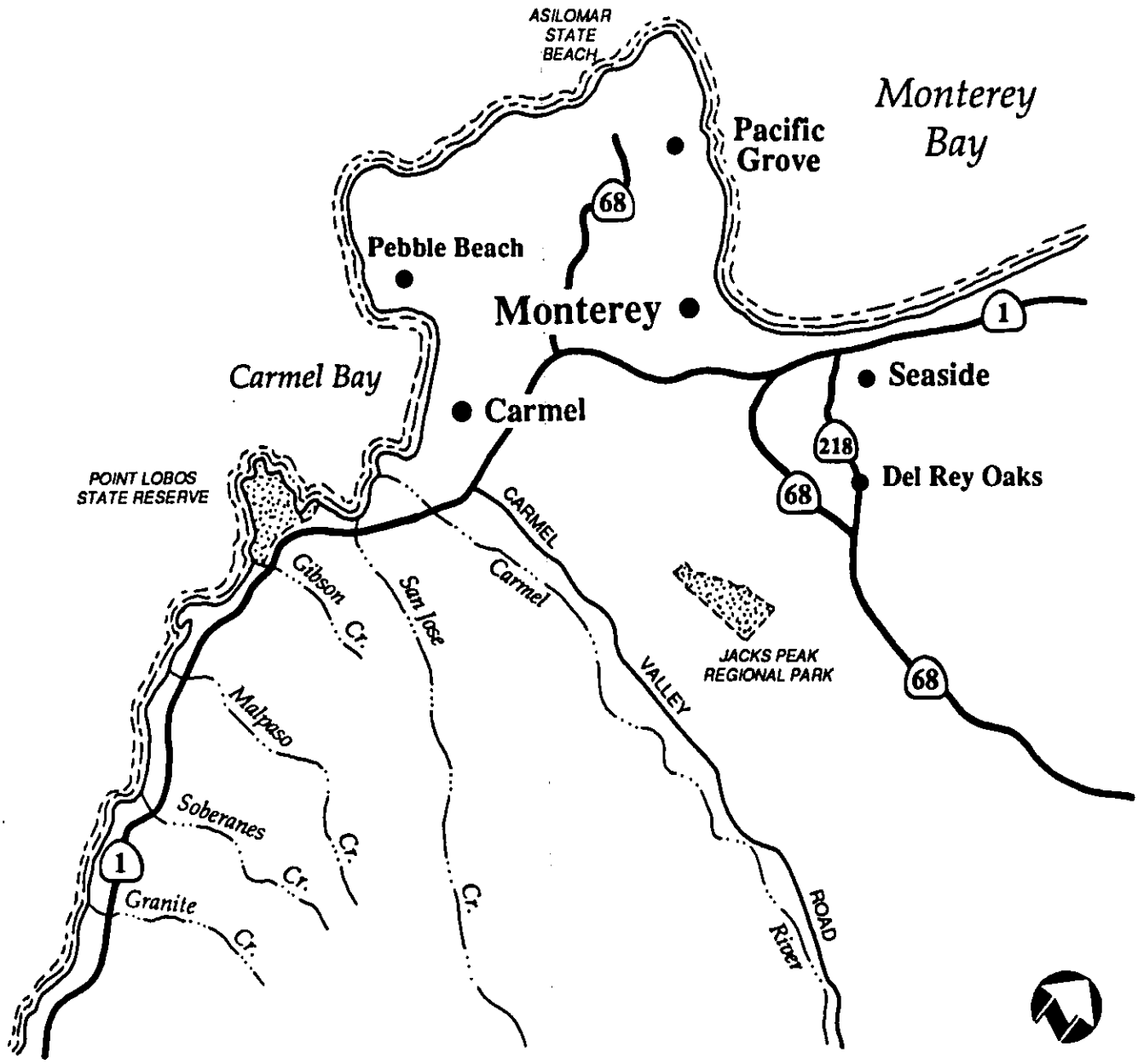

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Figure 1
Locator Map for Monterey Peninsula and Vicinity

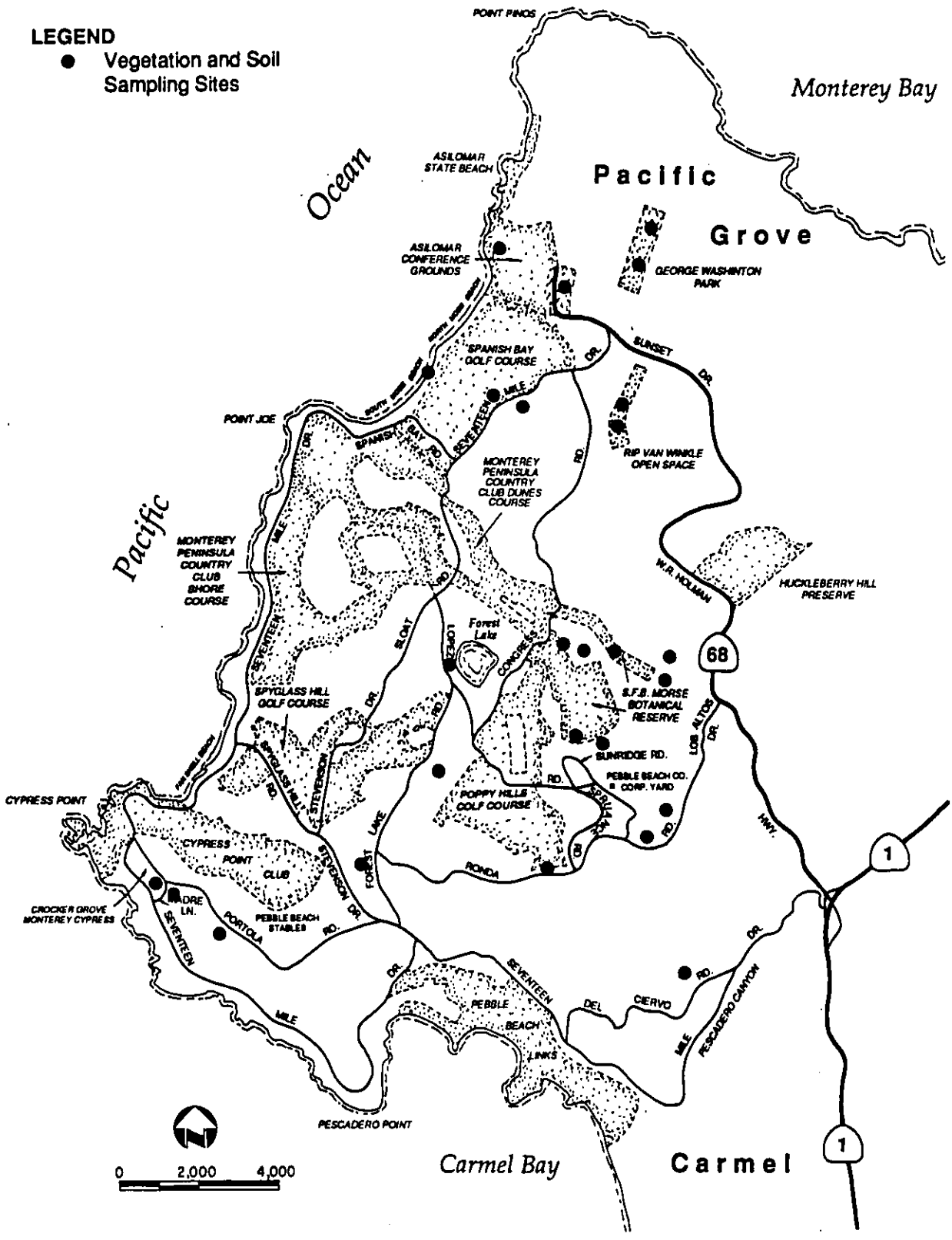

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Figure 2
Locator Map for Monterey Peninsula

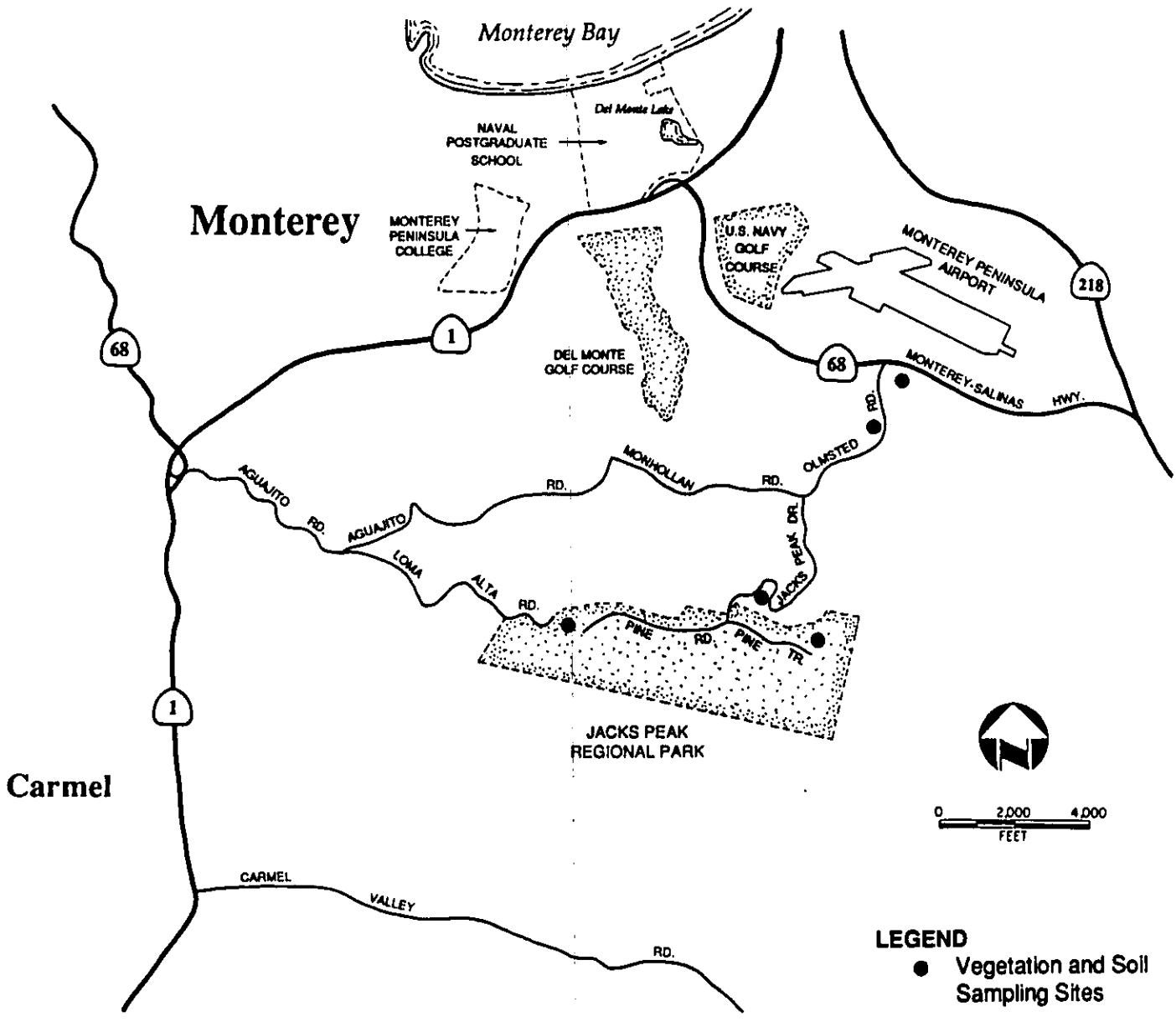

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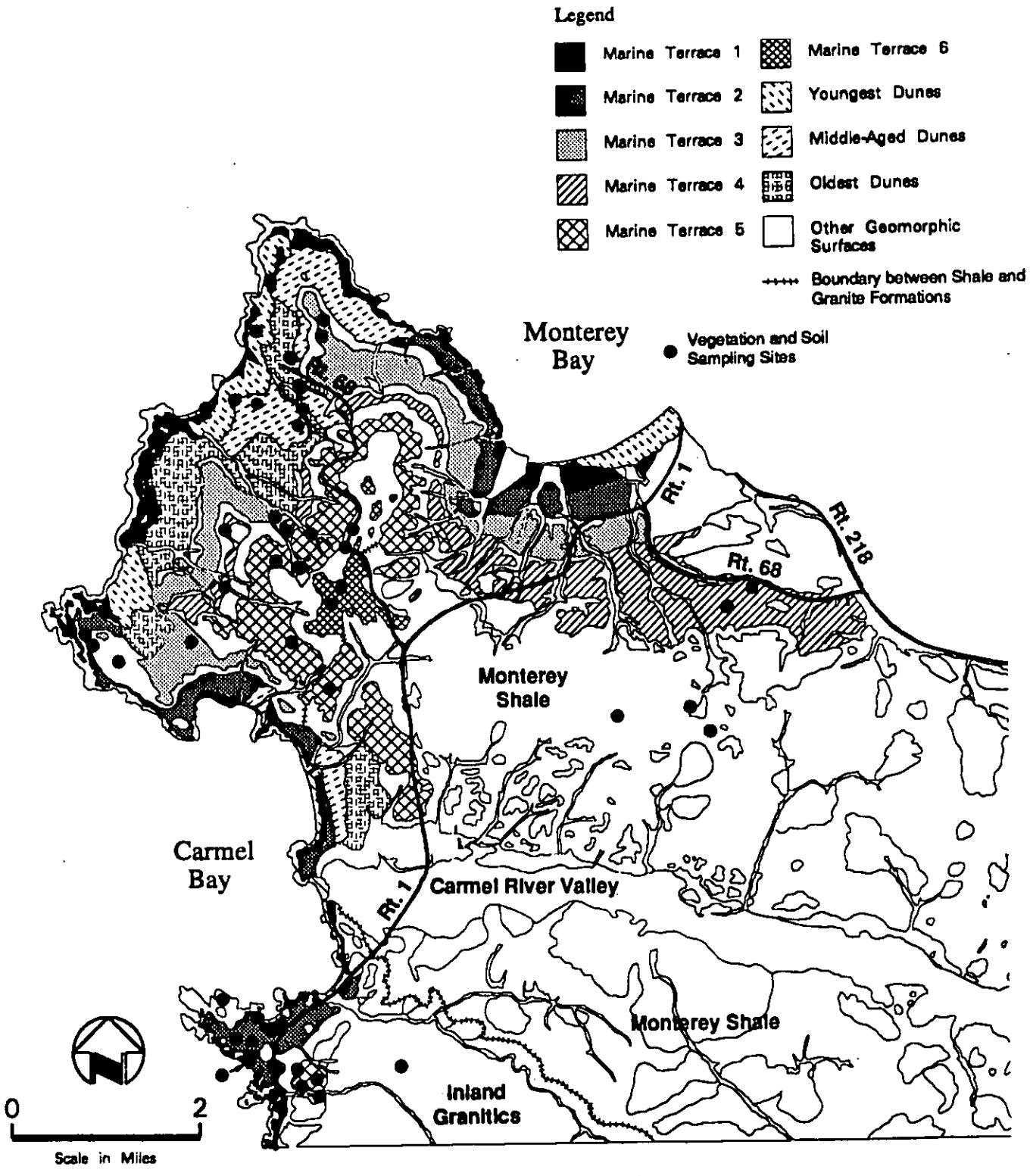
Figure 3
Locator Map for Inland Portion of Study Area



Source: Modified from Dupre 1990.

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Figure 4
Geomorphic Surfaces of the Monterey Peninsula

- inland geologic formations, and
- drainages.

Marine Terraces

Six marine terraces are identified by Dupré (1990). These are numbered from 1 to 6, starting with the lowest, youngest terrace nearest the ocean and increasing in elevation and distance from the coast in a "staircase" fashion. The marine terraces are identified in this report as:

- Marine Terrace 1 = Terrace 1 = Lighthouse Coastal Terrace,
- Marine Terrace 2 = Terrace 2 = Ocean View Coastal Terrace,
- Marine Terrace 3 = Terrace 3 = Peninsula College Coastal Terrace,
- Marine Terrace 4 = Terrace 4 = Silvan Coastal Terrace,
- Marine Terrace 5 = Terrace 5 = Monte Vista Coastal Terrace, and
- Marine Terrace 6 = Terrace 6 = Huckleberry Coastal Terrace.

Under this naming system, the present intertidal coastal terrace at sea level is "Terrace 0." Terrace 0 is composed of bare granite or other bedrock without an overlaying soil and supports tidepool plants and animals.

Intervening Slopes between Marine Terraces

The intervening slopes between terraces are defined by the terraces that surround them. For example, the intervening slope between Terraces 1 and 2 is called the "slope between Terraces 1 and 2."

Dunes

Three major dune systems occur on the Monterey Peninsula. These are the recent dunes of the Holocene Epoch referred to in this report as the "youngest dunes"; dunes deposited in the late Pleistocene Epoch referred to in this report as "middle-aged dunes"; and dunes of the middle to late Pleistocene Epoch referred to in this report as the "oldest dunes." Estimates of dune ages are based on Dupré (1990).

Inland Geologic Formations

Two major inland geologic formations are recognized for the purpose of this study. These are areas underlaid by or supporting exposed shale or granite bedrock referred to in this report as "shale bedrock" and "granite bedrock" formations.

Drainages

Drainages do not follow the organized spacial patterns of the other geomorphic surfaces. Drainages cut though all of the geomorphic surfaces described above. Because water removes, introduces, and modifies surface material, drainages are dealt with as a separate geomorphic surface in this study.

MATERIALS AND METHODS

Field surveys of soil and vegetation were conducted in the Monterey area on February 15-16 and March 24-27, 1994 (Figures 2, 3, and 4). Soil and vegetation surveys were conducted concurrently at the same locations and the relationships between soils and vegetation were described.

Soils

The original sources of information for the geomorphic and soil associations of Monterey pine forest subtypes were a recently published geologic map of the Monterey area (Dupré 1990), the soil survey of Monterey County (Cook 1978), and analogy with the soil-vegetation relationships of the famous Mendocino staircase of marine terraces and associated dunes (Jenny et al. 1969). Fieldwork to describe and identify soil profiles was then conducted according to National Cooperative Soil Survey standards to verify and provide support for the following discussion.

Vegetation

The purpose of the vegetation surveys was to characterize vegetative communities that represent the major vegetative cover of each geomorphic surface. Examples of vegetation were described from mature stands of relatively undisturbed vegetation. Recently disturbed sites were used to describe successional patterns (see "successional patterns" below). Vegetation was characterized at sites away from the edges of geomorphic surfaces to avoid the influence of adjacent vegetation (i.e., ecotones were avoided).

Vegetation surveys were conducted at sites where vegetation and ground disturbance appeared to be minimal. At least two sites supporting natural vegetation on each geomorphic surface were surveyed for vegetation (Figure 4). Vegetation was sampled and characterized visually. At each site, estimates were made of the relative cover of dominant understory shrub species and the absolute shrub cover relative to grass and open ground. Common understory species that are not part of the dominant cover were listed for each site. Overstory composition was recorded and sites were characterized as open or closed

canopy and multistoried or even-aged. The stature of Monterey pines was observed with special note made of stands with stunted trees (pines that were flat topped at less than about 70 feet in height). Trunk diameters of large pines were measured at breast height and the range of trunk diameters estimated. The presence of Monterey pine saplings and seedlings was noted. Regeneration was estimated to be good if large numbers of saplings and seedlings were observed and poor if few or none were seen. Line transects were conducted at five locations to describe understory cover, but because of the large number of sites to be characterized and the limited budget available, a rapid visual estimate of cover was the predominant technique. Overstory characteristics recorded in the field included:

- tree species present and their relative dominance,
- open versus dense canopy closure,
- apparent stunting of tree growth, and
- the presence of seedlings and saplings.

Understory vegetation characteristics recorded included:

- dominant shrub species present,
- common species present, and
- proportion of shrub cover to open understory cover of grass and duff.

Occasionally occurring species were also recorded if the species occurrence was unusual for the area or if the species was rare. Vegetation was sampled at locations throughout the Monterey Peninsula, Point Lobos State Park, Lobos Ranch, Jacks Peak Regional Park, and other inland locations (Figures 2, 3, and 4). The descriptions of vegetation provided for each geomorphic surface are based on the best examples of forest with natural understory observed on that surface with the characteristics of the largest and least disturbed sites emphasized.

Successional Patterns

Sites of recent fires and blowdowns were used to assess probable successional patterns on each geomorphic surface where examples of these events could be found. Species composition was recorded on these sites and compared to the composition of mature vegetation on adjacent sites on the same geomorphic surface.

RESULTS

Marine Terraces

Marine Terrace 1: Lighthouse Coastal Terrace

Marine Terrace 1 (Terrace 1) or the Lighthouse Coastal Terrace is the first terrace up from sea level and the youngest of the Pleistocene marine terraces at Monterey. The elevation range is generally from 10 to 40 feet. It runs in a nearly continuous band along the coastline from near Del Monte Lake in the Naval Postgraduate School in Monterey to the south side of Point Lobos.

In places along the Monterey Peninsula, Terrace 1 is covered by the youngest sand dunes; where beaches exist, they are lower in elevation and are between Terrace 1 and the ocean. Elsewhere the terrace no longer exists; along portions of the south side of the Monterey Peninsula and Point Lobos, the first terrace in from the ocean is Terrace 2, the Ocean View Coastal Terrace. The Lighthouse Coastal Terrace is being eroded by ocean waves since the rise in sea level after the most recent ice age. Eroded terrace remnants of the underlying granitic bedrock now extend out into the ocean from the existing terrace edge. The terrace is only a few hundred feet wide in places, but is up to 1,600 feet wide in the City of Monterey. Very little of this terrace remains in a natural condition; most of it has been developed or landscaped. Remaining segments along Point Lobos offer the best opportunity for study and prove to be of special interest as well.

Soils. Several soil types may be present on Terrace 1, some of which may show minimal pedogenesis (Cook 1978). One soil type that characterizes Terrace 1 along Point Lobos is a variant of the Antioch series. The Antioch series is a Typic Natrixeralf, but at Point Lobos the variant soil profile has the characteristics of a Typic Natralboll. It has the series standard subsoil horizon of clay accumulation with elevated sodium content; a natric horizon; and the colors indicative of leaching or depletion of iron below the surface horizon, known as an albic horizon. In addition, the profile has the dark colors of organic matter accumulation, a mollic epipedon, and the subsoil low matrix chroma with abundant high chroma mottles indicative of seasonal saturation, ponding within and above the claypan. Iron is reduced, translocated, concentrated, and oxidized under saturated conditions producing the observed color pattern.

The microtopography of the Terrace 1 in this location is a mound-intermound or depression pattern known as mima mounds that is characteristic of saline-sodic soils and is likely a result of compressive forces within the soil during the seasonal swelling of expansive, sodic clay upon rewetting. This mima mound microtopography is now prominent only on the south side of Point Lobos because of historic land use and surface alteration on the north side. In the depressions, the soil is a hydric soil indicative of a wetland; the mounds are dryer and less sodic, a condition that is indicated by the vegetation pattern.

To find a soil of this type directly adjacent to a coastline is highly unusual but may be explained as a relictual landscape. Sodic soils are actually common along the basin rim landscape position around and above both tidal and freshwater marshes, formed as a result of a complex biogeochemical process (Whittig and Janitzsky 1963). The occurrence of Antioch soil at Point Lobos may be understood as relictual of a rim bordering an estuarine tidal (or freshwater) marsh now covered and eroded by the waves of the rising sea.

Vegetation. Terrace 1 supports northern coastal scrub and coastal prairie vegetation. Northern coastal scrub and coastal prairie are described from examples at Point Lobos State Park.

Coastal scrub supports a dense shrub cover with a good mix of species. Dominant species are coyote brush (*Baccharis pilularis*, erect and prostrate forms), blue blossom (*Ceanothus thyrsiflorus*), California blackberry (*Rubus ursinus*), poison-oak (*Toxicodendron diversiloba*), and bush monkeyflower (*Mimulus aurantiacus*). Also common in the scrub community are Douglas' iris (*Iris douglasiana*), bracken fern (*Pteridium aquilinum* var. *pubescens*), golden yarrow (*Eriophyllum confertiflorum*), lizard tail (*Eriophyllum staechadifolium*), and California sagebrush (*Artemisia californica*).

Coastal prairie supports native perennial bunchgrasses, non-native annual grasses, and native and nonnative herbs. At Point Lobos State Park is a good example of coastal prairie with mima mound microrelief on Antioch soil. Here the mounds support bunchgrasses; native herbs, such as suncups (*Cammissonia ovata*) and star-tulip (*Calochortus uniflorus*); and prostrate coyote brush and bush monkeyflower shrubs on the tops of the mounds. Inter-mounds support saltgrass (*Distichlis spicata*), seaside plantain (*Plantago maritima*), and geranium (*Geranium dissectum*). The presence of saltgrass and seaside plantain indicate that the intermounds are likely moister and more saline than mounds.

Monterey cypress (*Cupressus macrocarpa*) and Monterey pine are unable to colonize the Antioch soil, possibly because of the saline-sodic condition. Elsewhere on other Lighthouse Coastal Terrace soil types, salt spray from the ocean may be sufficient to prohibit natural conifer colonization.

Successional Pattern. At some sites, northern coastal scrub and coastal prairie form distinct vegetative units that likely represent different soil types, while at other sites they intergrade. On some sites, coastal prairie may be seral to coastal scrub, depending on the frequency of fire or the presence of grazing.

Marine Terrace 2: Ocean View Coastal Terrace

Marine Terrace 2 or the Ocean View Coastal Terrace generally ranges in elevation from 40 to 120 feet. Therefore, a minimal or small elevation rise and short intervening slope distinguishes Terrace 2 from Terrace 1. Terrace 2 forms a less continuous band around the peninsula than Terrace 1; along much of the Monterey Peninsula, Terrace 2 is covered by the oldest sand dunes. A segment in the City of Monterey and Pacific Grove

is now entirely developed and landscaped. Fortunately, a large segment with the greatest width (over a mile) remains in natural condition on Point Lobos and extends to Lobos Ranch on the east side of Highway 1. Another smaller segment on the Monterey Peninsula, is the site of the Crocker Grove of Monterey cypress. In this study, some of the ocean bluffs that support Monterey cypress at Point Lobos State Park are included as part of Terrace 2, although these sites were not labeled as such in Dupré (1990).

Soils. Two distinctly different soil types are characteristic of Terrace 2, and the two vegetation communities of Monterey pine and Monterey cypress forest associate with the two soil types respectively. The Monterey pine forest occurs on a variant of the Santa Ynez soil series. The Santa Ynez series is typically an Ultic Palexeroll, but on Point Lobos it is a Xeric Argialboll. The soil profile has the dark-colored surface horizon of organic matter accumulation (mollic epipedon), the acidic subsurface horizon of leaching or depletion of iron and clay (albic horizon), and the abrupt transition to a very low permeability claypan (a paleo-argillic horizon) that are characteristic of the series. In addition, the variant series profile has the low chroma matrix and abundant high chroma mottles indicative of seasonal saturation, ponding within and above the claypan. Further, some profiles have abundant, large concretions known as durinodes.

Albic horizons are one of the primary soil features that characterize the Monterey pine soils of the marine or coastal terraces. An albic horizon is defined as soil material with the color of primary mineral sand and silt particles. Clay and/or free iron oxides have been removed or the oxides have been segregated from the matrix material into mottles or concretions (SCS 1992). The pedogenic process that creates albic horizons was previously termed podzolization, a soil science term that is now considered obsolete (SSSA 1987). The complexity of podzolization is now more fully understood, and subclassifications are made. Spodosols or soils with albic and spodic horizons are now distinguished in recognition of the pedogenic process of cheluviation or eluviation by chelation of aluminum and/or iron with fulvic acids (Fanning and Fanning 1989). Albic horizons may also form from other processes, such as lessivage (clay translocation) and gleization (reduction under saturated conditions). Evidence presently available indicates that albic horizons of the Monterey coastal terraces are formed by lessivage and gleization, and not by cheluviation.

The presence of redoximorphic concentrations (hydric mottles) and iron-manganese concretions lends support to this view. If the concretions are also weakly cemented or indurated by silica, they qualify as durinodes (SCS 1992). The formation of durinodes may be understood as the result of repeated cycles of soil saturation/desiccation with resulting gleization processes over geologically long time periods. In fact, all stages in this evolutionary process may be seen in the various soil profiles of the Monterey Peninsula area.

In addition to the above characteristics, Monterey pine coastal terrace soils are medium acid to extremely acid and moderate to very low in fertility. The Santa Ynez series is distinguished in part by medium acidity changing to mild alkalinity in the lower subsoil (Cook 1978), a thicker mollic surface horizon, moderate fertility, and a finer surface texture (sandy loam).

The soil series on which Monterey cypress grow is markedly different from the Santa Ynez series. First, it has formed in decomposed granite bedrock, instead of marine sand and clay sediment. There is no albic horizon, no claypan, no mottles or other hydric features. Soil pH is medium acid to neutral. Permeability is moderately rapid. The surface horizon is a thick mollic epipedon, ranging from 20 to 40 inches thick (Cook 1978). The soil is the Sheridan series and is classified as a Pachic Haploxeroll. Farther inland, away from the near-shore microclimate, Monterey pine forest may also occur on the Sheridan soil series.

Vegetation. Terrace 2 supports Monterey pine forest except at the ocean edge. Sheridan soils on the ocean bluffs support forests of Monterey cypress. Monterey pine forest and Monterey cypress forest are described from examples at Point Lobos State Park and Cypress Point.

Monterey pine forest on Terrace 2 may support nearly pure stands of Monterey pine or a mix of pine and coast live oak (*Quercus agrifolia*) (Table 1 and Figure 5). The mature forest canopy can be dense. The pine and oak occur in multi-aged stands and pine regeneration is good. The understory is a carpet of low shrubs that open up at some sites to a cover of duff and grass. The dominant understory shrubs are poison-oak and bush monkeyflower. Other common species present include California blackberry, California coffeeberry (*Rhamnus californica*), blue blossom, Coyote brush, Douglas' iris, fuchsia-flowered gooseberry (*Ribes speciosum*), and California polypody (*Polypodium californicum*).

Monterey cypress forest typically supports pure stands of Monterey cypress. Very old Monterey pine are mixed with a multi-aged stand of cypress at Crocker Grove on Cypress Point. The Monterey cypress forest understory supports sparse shrub and grass cover where the canopy is more open and very low vegetative cover, mostly duff, where the canopy is dense. Understory species include bush monkeyflower, hedge-nettle (*Stachys bullata*), California blackberry, Douglas' iris, snowberry (*Symphoricarpos mollis*), poison-oak, and swordfern (*Polystichum munitum*). Some shady sites support a dense cover of hedge-nettle.

Successional Pattern. Frequent ground fires have been set by the California Department of Parks and Recreation (DPR) at Point Lobos State Park in parts of the Terrace 2 Monterey pine forest. The fire has killed many mature trees and these trees have been blown down by recent storms. In the openings where recent burns and blowdowns have occurred, Monterey pine and shrub regeneration is dense. Dominant shrubs present in these openings are bush monkeyflower, poison-oak, blue blossom, and coyote brush. These are the same shrubs that dominate or are common in the understory of mature forest.

Marine Terrace 3: Peninsula College Coastal Terrace

Marine Terrace 3 or the Peninsula College Coastal Terrace generally ranges in elevation from 140 to 220 feet. It extends in a discontinuous band from near the intersection of state route (SR) 1 and SR 68 to Pebble Beach on the south side of the Monterey Peninsula. The elevation range is lower for the City of Monterey segments. The

Table 1. Understory and Overstory Characteristics of Monterey Pine Forest Subtypes on Marine Terraces

Terrace Community[a]	Understory		Overstory		Monterey Pine	
	Dominants	Shrub Cover (%)	Dominants	Canopy Closure	Height	Regeneration
Terrace 2						
MPF	Poison-oak; bush monkeyflower	50-80	Monterey pine or Monterey pine-oak	Closed	Full	Good
Terrace 3						
MPF	Grass; poison-oak	10-40	Monterey pine-oak	Open	Full	Fair to good
Terrace 4						
MPF	Shaggy-barked manzanita; huckleberry	40-60	Monterey pine	Closed	Stunted	Good
MPF	Grass; shaggy-barked manzanita	20-30	Monterey pine	Open	Stunted	Poor
MPBPF	Shaggy-barked manzanita	50-80	Monterey pine; Bishop pine	Open	Stunted	Good
Terrace 5						
MPF	Shaggy-barked manzanita; Hooker's manzanita; grass/duff	20-30	Monterey pine	Open	Stunted	Good
MPBPF	Shaggy-barked manzanita; Hooker's manzanita	50-80	Monterey pine; Bishop pine	Open	Stunted	Good
PyF	Shaggy-barked manzanita; huckleberry	50-80	Bishop pine; Gowan cypress	Open to Closed	Severely stunted	Poor

Table 1. Continued

Terrace Community[a]	Understory: Dominants	Understory: Shrub Cover (%)	Overstory: Dominants	Overstory: Canopy Closure	Monterey Pine: Height	Monterey Pine: Regeneration
Terrace 6						
MPF	Huckleberry; shaggy-barked manzanita	50-80	Monterey pine	Closed	Stunted	Good

[a] Community classifications:

MPF = Monterey pine forest.
MPBPF = Monterey pine-Bishop pine forest.
PyF = pygmy forest.

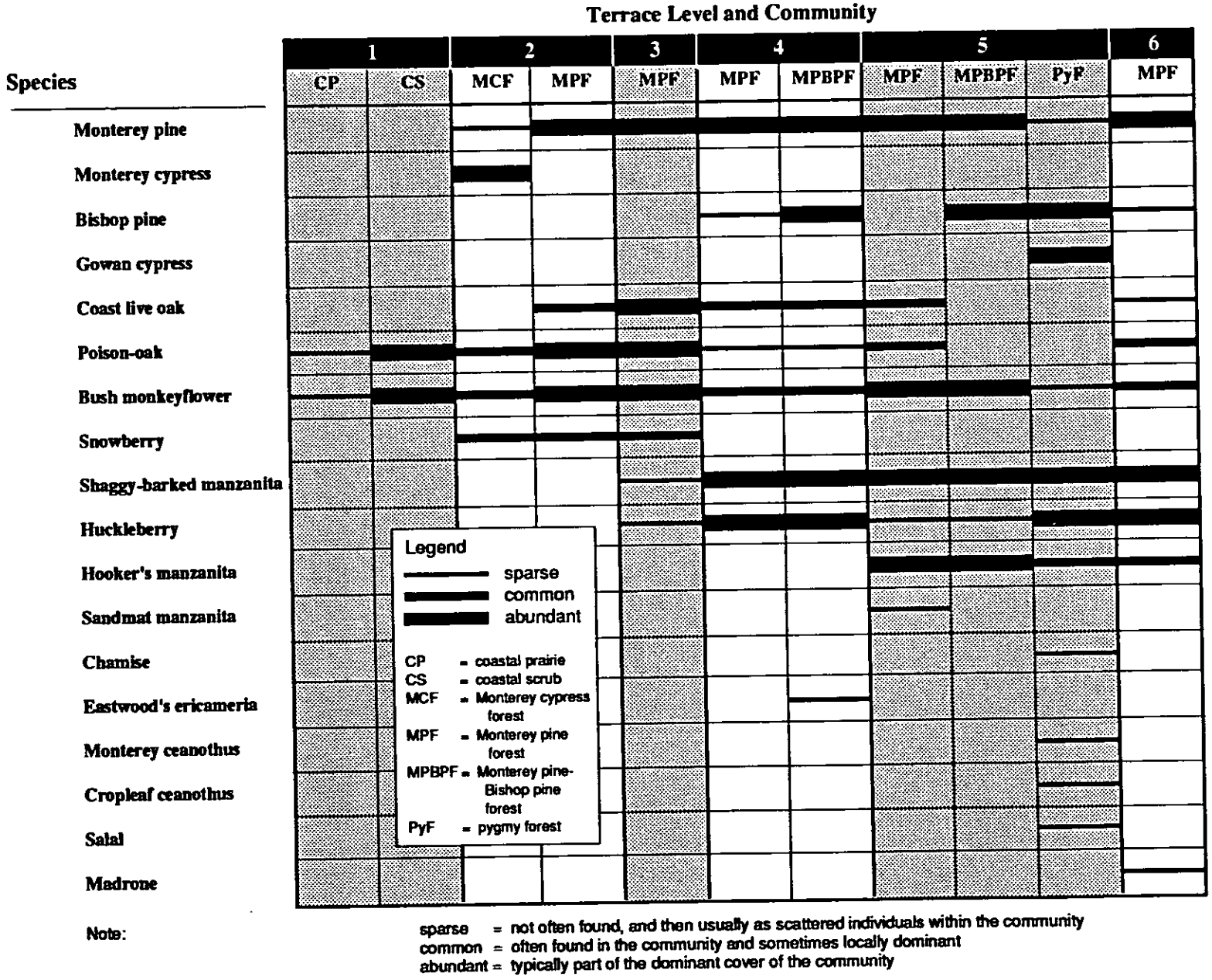

Figure 5.
Distribution of Selected Trees and Shrubs in Mature Vegetation on Marine Terraces

terrace is divided into segments by numerous stream channels that have eroded canyons and formed riparian corridors in the underlying marine sediment and decomposed granitic bedrock. A large section above Spanish Bay on the Monterey Peninsula is covered by older sand dunes. The width of Terrace 3 is up to 3,600 feet at the Pebble Beach riding stables.

Almost all of Terrace 3 has been developed and landscaped. Three small natural to semi-natural areas were sampled: part of George Washington Park in Pacific Grove, the western tip of the S.F.B. Morse Botanical Reserve, and a narrow strip on the southeast side of the Pebble Beach riding stable. It is not known at this time if any portion of Terrace 3 remains in the Lobos Ranch area east of Point Lobos.

Soils. The primary soil type characteristic of Terrace 3 is the Narlon series, a Typic Albaquult. It has most of the characteristics of the Santa Ynez series, but differs in having a more strongly leached albic horizon; stronger acidity and lower fertility throughout the soil profile; and a thin, dark-colored surface horizon too shallow to be a mollic epipedon. The pH ranges from medium acid to extremely acid, although Terrace 3 soil pH is primarily in the medium acid range. Depth to claypan is widely variable, ranging from 16 to 56 inches. Surface or A horizon thickness is typically 3 inches, with a 2-inch-thick O horizon or litter layer. The soil everywhere exhibits redoximorphic features of a hydric soil; saturation of the subsoil above the claypan was observed at the S.F.B. Morse Botanical Reserve site at the time of sampling following a rainstorm.

The soil profile described at George Washington Park is intermediate between the Narlon series and the Oceano and Arnold soil series characteristic of the oldest dunes. The park itself straddles the landform transition between Terrace 3 and the oldest dunes. The soil profile has thin claypan bands up to 2 inches thick underlying an albic horizon and overlying a weakly iron-cemented hardpan. This hardpan has features of a spodic horizon but may not meet all criteria of the present definition. The Oceano and Arnold soil series are described in further detail in the oldest dune section below.

Vegetation. Terrace 3 supports a forest of Monterey pine and coast live oak. Examples of natural Monterey pine forest on Terrace 3 were sampled near the Pebble Beach Stables, George Washington Park, and at the S.F.B. Morse Botanical Reserve. Disturbance of understory vegetation has occurred at the Pebble Beach riding stables and George Washington Park sites. The site at the S.F.B. Morse Botanical Reserve is a small remnant of Terrace 3 wedged between two drainages. Probably none of the sites surveyed on Terrace 3 support typical Terrace 3 vegetation, but hints of the natural cover are provided by small patches of less disturbed vegetation at George Washington Park and near the Pebble Beach riding stables.

On Terrace 3, the Monterey pine forest canopy is relatively open and some stands may be woodland with a grass understory rather than a closed forest (Table 1 and Figure 5). Pines range from seedlings to large trees. Coast live oak is a common associate. In woodlands, the understory is mostly bunchgrasses and has the look of coastal prairie. European annual grasses, especially ripgut brome (*Bromus diandrus*), dominate other sites. Shrubs are sparse, occurring in dense patches. Where poison-oak is present, it forms a

dense carpet and is the dominant shrub. Where the understory is mostly duff (likely disturbed sites) California blackberry is the dominant cover. Other common shrubs are bush monkeyflower, blue blossom, and snowberry. Hedge-needle can be locally dominant at sites with a closed forest canopy. Common herbaceous species present include bracken fern, yarrow (*Achillea millifolium*), Douglas' iris, spreading common rush (*Juncus patens*), blue wildrye (*Leymus glaucus*), giant wildrye (*Leymus condensatus*), California bedstraw (*Galium californicum*), star lily (*Zygadenus fremontii*), coast sanicle (*Sanicula laciniata*), California strawberry (*Fragaria vesca* spp. *californica*), and Bermuda buttercup (*Oxalis pes-capre*).

Upper edges of Terrace 3, near the intervening slopes between Terraces 3 and 4 support an understory of shaggy-barked manzanita (*Arctostaphylos tomentosa* var. *tomentosa*) and huckleberry (*Vaccinium ovatum*). However, the site observed was small and strongly influenced by surrounding Monterey pine riparian forest.

The understory vegetation in the sites used to characterize Monterey pine forest on Terrace 3 either have been continually disturbed by human and horse traffic or are not characteristic of the central portion of this geomorphic surface. Based on observations and inference, the probable dominant understory cover without disturbance is a carpet of poison-oak and bush monkeyflower mixed with grassy openings, much as on Terrace 2.

Successional Pattern. Sites with recent fire disturbance were not observed for Terrace 3. Possibly, the dense grass cover, especially tall European annual grasses, may reduce seedling establishment of Monterey pine (Moss pers. comm.).

Marine Terrace 4: Silvan Coastal Terrace

Marine Terrace 4 or the Silvan Coastal Terrace generally ranges in elevation from 240 to 300 feet. It extends in a discontinuous band from south of the Monterey Peninsula Airport to north of Pebble Beach between the Spyglass Hill and Poppy Hills Golf Courses. Elevation ranges are somewhat lower for the segments in and adjacent to the City of Monterey. Terrace 4 is also divided into many segments by canyons and riparian corridors and is covered by older sand dunes in a segment south of Rip Van Winkle Open Space. The width of Terrace 4 is up to a mile or more, south of the Monterey Peninsula Airport, but is generally only 200-800 feet wide on the Monterey Peninsula itself. As with Terrace 3, almost all of it has been developed and landscaped, with few natural areas remaining. Three small natural to semi-natural areas were sampled: on the terrace south of the Monterey Peninsula Airport, in the S.F.B. Morse Botanical Reserve, and on the northwest side of Forest Lake (a reservoir excavated out of the Silvan Terrace). It is not known at this time if any portion of Terrace 4 remains in the Lobos Ranch area east of Point Lobos.

Soils. The primary soil type of Terrace 4 is the Narlon series also found on Terrace 3. Soil characteristics are generally in the same range, with typically large depths of 3-3.5 feet to the claypan, A horizons of 2 inches or less, and medium acid soil pH. Depth to redoximorphic features is 15 inches or more.

At least two other soil types are found on this terrace. One is an undescribed series that will provisionally be termed the Sunridge series. It has formed in decomposed granitic bedrock, but has a weakly to strongly iron-cemented hardpan at a shallow depth of 1-2 feet. One of three profiles shows a slight subsoil clay accumulation but this is insufficient for an argillic horizon. The profiles do not have redoximorphic features of hydric soils. The hardpan is suggestive of a spodic horizon but may not meet the present criteria; the Sunridge series does not appear to have an albic horizon. Sufficient profile descriptions and laboratory analysis are not available to properly classify this soil, but it will be given a preliminary classification of a Dystric Entic Durochrept.

On Terrace 4 segments along SR 68 south and southwest of the Monterey Peninsula Airport, the source of alluvium is not decomposed granite, but the shale of the Monterey Formation. The soil type is the Chamise series, an Ultic Argixeroll. The distinguishing features are a moderately deep mollic epipedon, 12 to 20 inches thick, an argillic horizon of subsoil clay accumulation, and a soil pH of very strongly acid to neutral. The soil profile has no redoximorphic features of a hydric soil (Cook 1978). The difference in soil type is reflected in a vegetation change; existing vegetation is grassland, oak woodland and savannah, and Monterey pine forest (see vegetation description below).

Vegetation. Few remnants of Terrace 4 with natural vegetation remain on the Monterey Peninsula. A large piece of Terrace 4 with natural vegetation occurs inland along SR 68 east of Olmsted Road. Sites supporting natural vegetation on Terrace 4 were surveyed along Lopez Road at Forest Lake, S.F.B. Morse Botanical Reserve, and at the corner of SR 68 and Olmsted Road.

On the peninsula, Terrace 4 Monterey pine forest can have an open or closed canopy (Table 1 and Figure 5). Coast live oak is an occasional to common associate. At some sites, Bishop pine (*Pinus muricata*) grows mixed with Monterey pine in open canopy stands. Monterey pines on Terrace 4 appear to be stunted in height, becoming flat topped at about 50-70 feet tall. The understory may be grassland with scattered patches of dense shaggy-barked manzanita or more uniform shrub cover with a mix of shaggy-barked manzanita, huckleberry, California coffeeberry, bush monkeyflower, and blue blossom. Other species present include coyote brush, Douglas' iris, yarrow, poison-oak, California blackberry, small-leaved lomatium (*Lomatium parvifolium*), and California strawberry.

The Terrace 4 site along SR 68 is on shale deposits rather than granite, and the vegetation is not expected to be similar to the other examples of Terrace 4 vegetation. The vegetation at this site includes a Monterey pine forest with a strong component of coast live oak, oak woodland and savanna, and grassland. The grasslands at this site are managed for grazing, and oak and pine regeneration may be suppressed. The Monterey pine forest on Terrace 4 along SR 68 appears to be near the inland limit for lowland Monterey pine forest. Monterey pine forest occurs farther inland on the shale bedrock formation on the hills above this site.

Successional Patterns. Sites with recent fire disturbance were not observed for Terrace 4. The Forest Lake site supports Monterey pine of distinct sizes that are apparently

two age cohorts. The older Monterey pine are about 50-70 feet tall and 12-24 inches dbh and the younger Monterey pine about 20-30 feet tall and 6-11 inches dbh. The older pine are likely fire survivors, and the younger pine are the regeneration following the last fire.

Marine Terrace 5: Monte Vista Coastal Terrace

Marine Terrace 5 or the Monte Vista Coastal Terrace generally ranges in elevation from 320 to 540 feet. It forms a partially continuous band around Huckleberry Hill with an extension south to the east side of Carmel. A segment of Terrace 5 also occurs on the inland hillslopes of Lobos Ranch east of Point Lobos. The Terrace 5 is cut by stream canyons but is not covered by old sand dunes. Terrace width is as much as 3,200 feet. It is the best preserved of the six terraces; large undeveloped and unlandscaped areas remain. In addition, it is the only terrace that contains pygmy forest.

Soils. The Narlon series and Sunridge series occur on the Terrace 5. A third undescribed soil series, similar to the Narlon series and provisionally termed the Huckleberry series, also occurs and will be described below.

Variations in Narlon series soil characteristics on Terrace 5 can be correlated with vegetation changes from Monterey pine forest to pygmy Bishop pine forest to pygmy Gowan cypress forest. The soil characteristics that vary are depth of litter layer or O horizon, thickness of A Horizon, depth to redoximorphic features, depth to claypan, and soil pH. Depth of the O horizon varies from 1 inch to less than one-eighth inch; less than one-half inch is indicative of pygmy forest. The A horizon thickness ranges from 3 to 0 inches, with the pygmy forest average closer to 0, but A horizons at the thicker end of the range may also be found in the pygmy forest. Depth to redoximorphic features ranges from 16 to 0 inches, with the pygmy forest depth averaging close to 0, but again with some variability. Concretions, as well as other redoximorphic features, are usually abundant. Depth to claypan in the pygmy forest is typically less than 20 inches and as shallow as 4 inches. Soil pH in the pygmy forest is typically in the strong to extremely acid range. The criteria presented are estimates of general soil characteristic variations based on a few observations and are intended to illustrate overall trends, not specific limiting ranges.

The Huckleberry series is similar to the Narlon series, except for the addition of an important new pedogenic process and material: laterization and plinthite, respectively. Laterization is the accumulation of iron oxides, principally hematite, in a subsoil horizon by eluviation in reduced form from elsewhere. Aluminum is relatively immobile in this process. Gleization or even sulfuricization may be contributory pedogenic processes. The iron oxidizes and concentrates in a reticulate, vesicular or nodular form, and while still in a softened state is referred to as plinthite (Fanning and Fanning 1989). Plinthite is a mixture of clay with quartz and other dilutents that is rich in iron and poor in humus or organic matter. It is characterized by a very dark red color; on Terraces 5 and 6 it is indicated in segregations of 10R 3/6 in color, the reddest color in the Kollmorgen Corporation (1975) soil color charts. The Huckleberry soil series with plinthite may be classified as a Plinthic Palehumult (in analogy to a very similar soil of the Mendocino staircase).

Repeated wetting and drying irreversibly hardens plinthite into a cemented pan known as ironstone, especially if it is also exposed to the heat of the sun. The hardpan is then referred to as a petroferric horizon (SCS 1992). This process has occurred in the pygmy forest where roadcuts have exposed the plinthitic claypan to the sun and repeated wetting and drying. The ironstone hardpan is impervious to water, and the resulting increase and channelization of runoff is resulting in erosion gullying in the roadbeds and downslope where cementation has not taken place. Plinthite and the process of hardening into ironstone also occurs in some tropical rainforest soils.

Vegetation. Sites supporting natural vegetation on Terrace 5 were surveyed at the Pescadero Tract on Del Cierro Road, the corner of Viscaino and Rhonda Roads, the Pebble Beach Company Corporate Yard, the S.F.B. Morse Botanical Reserve, and Lobos Ranch near Gibson Creek. Vegetation on Terrace 5 was divided into three phases: Monterey pine forest, Monterey pine-Bishop pine forest, and pygmy forest (Table 1 and Figure 5).

Monterey Pine Forest. Monterey pine forest on Terrace 5 supports an open canopy of Monterey pine with coast live oak. The pines are stunted, becoming flat topped at about 50-60 feet tall. Stands are multistoried and pine regeneration is good. The understory is a mix of open grass and duff with patches of dense shrubs. Shrub cover is a fairly even mix of shaggy-barked manzanita, Hooker's manzanita (*Arctostaphylos hookeri* var. *hookeri*), sandmat manzanita (*Arctostaphylos pumila*), California coffeeberry, bush monkeyflower, poison-oak, and coyote brush. The soils supporting Monterey pine forest on Terrace 5 are deeper (about 24 inches to the top of claypan versus 4-20 inches for pygmy forest) than in the Monterey pine-Bishop pine and pygmy forests on Terrace 5 (see below).

Monterey Pine-Bishop Pine Forest. Monterey pine-Bishop pine forest supports a mix of Monterey pine and Bishop pine in open stands. The Monterey pine are stunted in height but form the canopy above a subcanopy of Bishop pine and smaller Monterey pine. The understory is an even mix of shrubs. The dominant shrubs are shaggy-barked manzanita, Hooker's manzanita, coyote brush, and bush monkeyflower.

Pygmy Forest. The dominant trees in pygmy forest are Bishop pine and Gowan cypress (*Cupressus goveniana* spp. *goveniana*). These trees are typically 10-25 feet tall. Monterey pine are sometimes scattered through the pygmy forest. The Monterey pine grow taller (about 20-30 feet tall) than Bishop pine or Gowan cypress, but are severely stunted from their normal height. The understory in mature pygmy forest is dominated by shaggy-barked manzanita and huckleberry, with occasional California coffeeberry.

Open canopy stands of pygmy forest support a more diverse shrub understory, including shaggy-barked manzanita, Hooker's manzanita, chamise (*Adenostema fasciculata*), and huckleberry. Scattered individuals of bush monkeyflower, toyon (*Heteromeles arbutifolia*), and black sage (*Salvia mellifera*) may be present. Open canopy pygmy forest occurs at sites of recent fires and on the most shallow, severe pygmy forest soils.

The pygmy forest can be subdivided into three types: stands that support pure Bishop pine; stands that are a mix of Bishop pine and Gowan cypress; and stands that are nearly

pure Gowan cypress. Our preliminary evidence indicates that these types may represent a sequence in soil development with pure Gowan cypress occurring on the shallowest and most acidic soils, the mixed pygmy forest on intermediate soils, and Bishop pine pygmy forest on the least extreme of pygmy forest soils (Figure 6). See general soil characteristic variations listed in the soils section above. These data are in agreement with the conclusions of Griffin (1972) on pygmy forest-soils patterns.

Successional Patterns. Following fire on Terrace 5, trees and shrubs sprout from seed or resprout from root crowns within a few years. The diversity of shrub and herb species is much greater in early successional stages than in mature forests, but no classical succession of species occurs. All species present in the mature forest appear in the first few years following a fire. Common species in pygmy forest observed at a site that burned in 1987 included Bishop pine seedlings 3-6 feet tall, Gowan cypress seedlings 3-7 feet tall, shaggy-barked manzanita, Hooker's manzanita, huckleberry, salal (*Gautheria shallon*), chaparral currant (*Ribes malvaceum*), coyote brush, chamise, cropleaf ceanothus (*Ceanothus dentatus*), Monterey ceanothus (*Ceanothus cuneatus* spp. *rigidus*), Douglas' iris, bracken fern, bear grass (*Xerophyllum tenax*), lizard tail, and pampas grass (*Cortedaria* sp.). Mature stands of pygmy forest adjacent to this burn site are dominated by Bishop pine, Gowan cypress, shaggy-barked manzanita, and huckleberry with very few or no individuals of the species present in the burn site.

Marine Terrace 6: Huckleberry Coastal Terrace

Marine Terrace 6 or the Huckleberry Coastal Terrace generally ranges in elevation from 600 to 800 feet. It forms the summit cap in several segments on Huckleberry Hill. Terrace width is as much as 4,800 feet on the largest segment. Most of Terrace 6 has been developed, but remnant natural areas remain above the Pebble Beach Company Corporate Yard and in the S.F.B. Morse Botanical Reserve.

Soils. The primary soil series of the Terrace 6 is the Huckleberry series; small areas of the Narlon series may also occur. Soil characteristics are within the range for pygmy forest but no pygmy forest areas have been observed.

Vegetation. Mature stands of vegetation on Terrace 6 were observed near the intersection of Atajo Way and Rhonda Road and along Castanilla Way near Sunridge Road.

Terrace 6 supports Monterey pine forest in an open overstory (Table 1 and Figure 5). The pines are stunted at about 40 feet (flat topped). Scattered Bishop pines are present. The understory supports dense cover of huckleberry and shaggy-bark manzanita. On Terrace 6, huckleberry appears to be the most common shrub. Where the canopy is more open the understory supports Hooker's manzanita. Other common shrubs are bush monkeyflower, coyote brush, poison- oak, and California blackberry. Total shrub cover ranges from about 50 to 80% mixed with a grassy understory, including bunchgrasses. Very few coast live oak are found in these forests. Scattered individuals of madrone (*Arbutus menzeisii*) and Scouler's willow (*Salix scouleriana*) can be found in the forest.

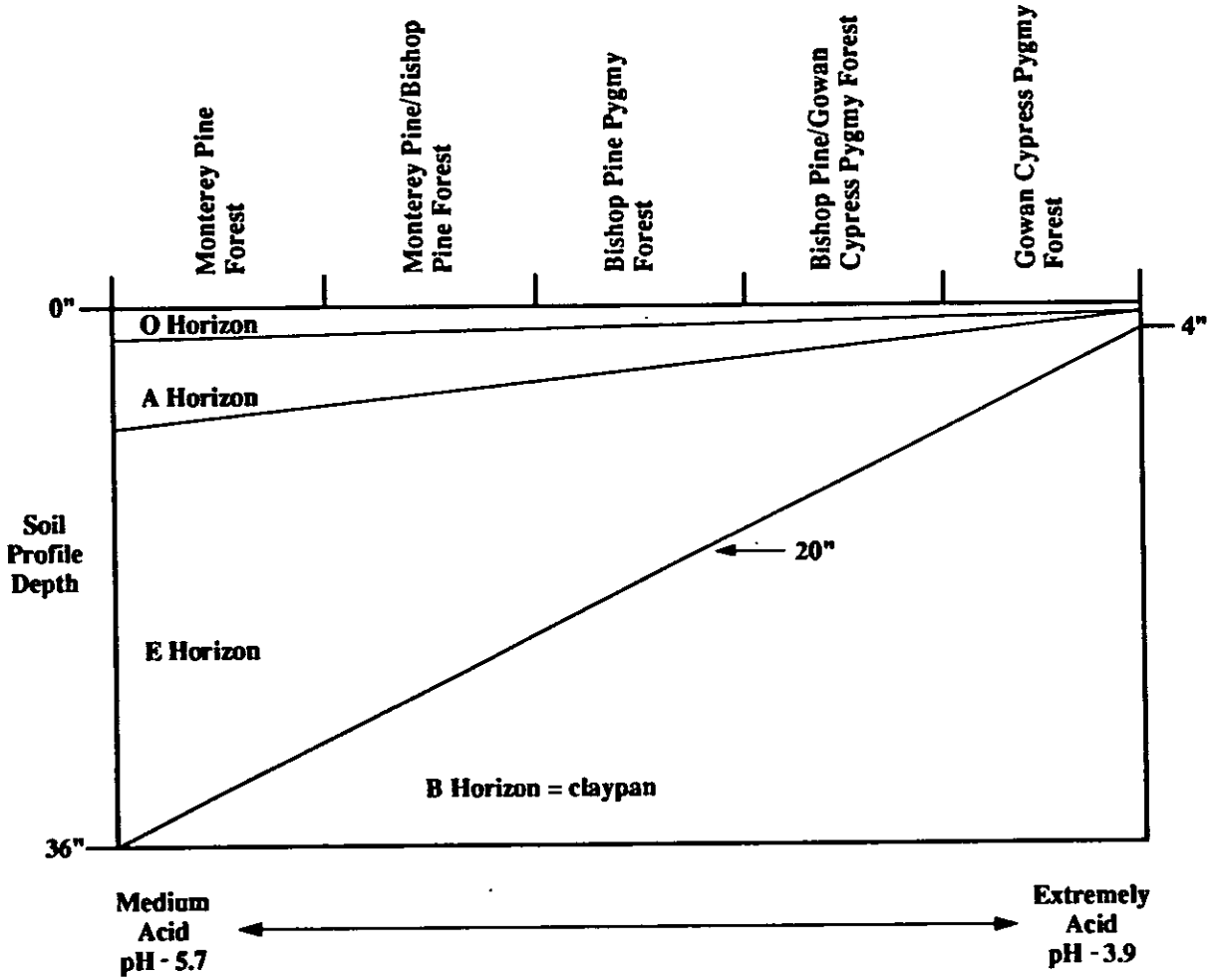

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Figure 6
General Vegetation Trends on Terrace 5 Soils

Successional Pattern. At a site on Terrace 6 that burned in 1987 Monterey pine regeneration was very dense. Among the dense pine seedlings is good regeneration of huckleberry, shaggy-barked manzanita, and coyote brush. It appears that all species that make up the mature forest reestablished immediately following fire. Also common at this burn site were opportunistic species such as cut-leaved fireweed (*Erechtites glomerata*), toothed fireweed (*Erechtites minima*), deerweed (*Lotus scoparius*), and pampas grass.

Intervening Slopes between Marine Terraces

Granitic Slopes between Terraces 1 and 2

Soils. As indicated above, only short, low slopes occur between Terraces 1 and 2. The slope soil was not sampled.

Vegetation. Vegetation on slopes between Terraces 1 and 2 was observed at Point Lobos State Park. Monterey pine occurs in pure stands on these slopes with coastal scrub or coastal prairie species in the understory (Table 2).

Successional Pattern. The site of a recent controlled burn followed by the blowdown of pines by a winter storm supported abundant regeneration of Monterey pine, coyote brush, blue blossom, bush monkeyflower, poison-oak, cut-leaved fireweed, toothed fireweed, and German ivy (*Senecio milkanioides*).

Granitic Slopes between Terraces 2 and 3

Soils. The soils on slopes between Terraces 2 and 3 have not been sampled but are most likely the Sheridan series, with inclusions of the associated Pfeiffer, Vista, and McCoy series on decomposed granitic bedrock (Cook 1978).

Vegetation. Vegetation on slopes between Terraces 2 and 3 was observed along Portola Road. Monterey pine forest occurs on these slopes (Table 2). Coast live oak occurs scattered among the pines. The understory is a carpet poison-oak and bush monkeyflower. A good grass cover is present, including bunchgrasses. Common shrubs are California coffeeberry, snowberry, and California blackberry.

Granitic Slopes between Terraces 3 and 4

Soils. The soils on slopes between Terraces 3 and 4 have not been sampled but are most likely the Sheridan series, with inclusions of the associated Pfeiffer, Vista, and McCoy series on decomposed granitic bedrock (Cook 1978).

Vegetation. Slopes between Terraces 3 and 4 were observed along Lopez and Viscaino Roads. These slopes support Monterey pine forest with an understory of shaggy-barked manzanita and huckleberry (Table 2). Coast live oaks are common.

Granitic Slopes between Terraces 4 and 5

Soils. Slopes between Terraces 4 and 5 on the northwestern side of Huckleberry Hill were observed to be of the Narlon and Huckleberry series. Other soil types may occur elsewhere.

Vegetation. Slopes between Terraces 4 and 5 were observed along Lopez, Spruance, and Midwood Roads and Lobos Ranch. These slopes support Monterey pine forest (Table 2). Coast live oak is common. The understory is dense shaggy-barked manzanita and huckleberry. Other common shrubs are California coffeberry, California blackberry, snowberry, and poison-oak.

Granitic Slopes between Terraces 5 and 6

Soils. Slopes between Terraces 5 and 6 on the northwestern side of Huckleberry Hill were observed to be of the Sunridge series, as well as the Sheridan and related series formed on decomposed granite. Elsewhere on these slopes, the contact zone between the granitic bedrock and the overlying shale bedrock of the Monterey Formation is crossed and the representative soil series is the Santa Lucia (described below under "Shale Bedrock").

Vegetation. Slopes between Terraces 5 and 6 were observed along Lopez, Spruance, and Midwood Roads. These slopes support Monterey pine forest (Table 2). Coast live oak is common. The understory is dense huckleberry and shaggy-barked manzanita. Huckleberry appears to be more abundant on these slopes than on slopes between Terraces 4 and 5. Very dense stands of Monterey pine on these slopes support an open understory of duff and California blackberry, with shaggy-barked manzanita and huckleberry restricted to light gaps.

Some of the slopes between Terraces 5 and 6 support Bishop pine forest. These forests are composed of nearly pure, dense stands of full-sized Bishop pine on slopes above the Bishop pine pygmy forest. Understory vegetation is sparse.

Successional Pattern. Sites that burned on the slopes between Terraces 5 and 6 in 1987 are densely populated with Monterey pine. Among the young pine are huckleberry, salal, coyote brush, and shaggy-barked manzanita. The dominant understory species are present immediately following fire and mature with the pine.

Other sites on these slopes that burned in 1987 support dense regeneration of Bishop pine. With the Bishop pine is a diverse assemblage of shrubs, including shaggy-barked manzanita, blue blossom, Monterey ceanothus, Hooker's manzanita, pitcher sage (*Lepechinia*

Table 2. Understory and Overstory Characteristics of Monterey Pine Forest Subtypes on Granite Slopes between Terraces

Slope Community[a]	Understory		Overstory		Monterey Pine	
	Dominants	Shrub Cover	Dominants	Canopy Closure	Height	Regeneration
Slopes between Terraces 1 and 2						
MPF	Grass; coyote brush; bush monkeyflower; poison-oak	Low to moderate	Monterey pine	Open to closed	Full	?
Slopes between Terraces 2 and 3						
MPF	Poison-oak; bush monkeyflower	Moderate to high	Monterey pine-oak	Closed	Full	Good
Slopes between Terraces 3 and 4						
MPF	Shaggy-barked manzanita; huckleberry	High	Monterey pine-oak	Closed	Full	?
Slopes between Terraces 4 and 5						
MPF	Shaggy-barked manzanita; huckleberry	High	Monterey pine-oak	Closed	Full	?
MPF	Duff and mixed shrubs	Moderate	Monterey pine-oak	Closed	Full	Good
Slopes between Terraces 5 and 6						
MPF	Huckleberry; shaggy-barked manzanita; duff	Low to high	Monterey pine-oak or Monterey pine	Closed	Full	Good
BPF	Duff	Low	Bishop pine (few Monterey pine)	Closed	Full	Poor

Table 2. Continued

* Community classifications:

MPF = Monterey pine forest.
BPF = Bishop pine forest.

calycina), chinkapin (*Castinopsis chrysphylla*), huckleberry, bush monkeyflower, and coyote brush. As the Bishop pine forest matures, the shrub diversity declines greatly.

Dunes

Sand dunes of different ages have accumulated on portions of Terraces 1 through 4. Within the study area, dunes are found inland from the northwest shoreline and northwest corner of the Monterey Peninsula, and also in Carmel and a small area of Pebble Beach.

Formations of dunes in four age groups, one from the Holocene and three from the Pleistocene, have been recognized in the Monterey pine area (Dupré 1990). The oldest group, known as Aromas sand, is of limited extent in the study area (found only in Carmel) and for the purpose of this report is grouped with the "oldest dunes" category. All four geomorphic dune classifications occur extensively on Fort Ord. See Jones & Stokes Associates (1992) for a description of the dune soil-vegetation relationships of Fort Ord. The division into dune formations is based on soil types, and the soil types that define the age sequence at Fort Ord also occur in the Monterey area. The soil types in order of increasing age are: active dunes (Typic Xeropsamments), Baywood, Oceano, Elkhorn, and Arnold soil series. A sixth soil type, the Tangair series, does not occur on Fort Ord, but does occur in the Monterey area. It most likely fits in between the Elkhorn and Arnold series in the age sequence, but its pedogenic processes are somewhat different. Monterey pine did not naturally occur on Fort Ord, but does or did occur naturally on all of the soil types in the Monterey area, except the Typic Xeropsamment.

The pedogenic processes involved in the evolutionary sequence of the sand dune soils include melanization (organic matter accumulation), lessivage, gleization, and laterization or possibly podzolization (as in both albic or albic/spodic horizon formation), all of which also occur on the terrace soils but with somewhat different results. The processes and resulting soils will be described for the respective dune formations below.

Youngest Dunes

Soils. The youngest dunes are the active dunes in the process of stabilizing and vegetating. Most areas of active (or recently active) dunes occur near the shoreline along the northwest side of the Monterey Peninsula. Many dune areas have been converted into golf courses and otherwise developed; the best preserved or restored areas are at the Asilomar Conference Grounds and along Point Pinos. The soil type is loose sand with no pedogenic development; such a soil type is a Typic Xeropsamment. Primary soil characteristics are very high permeability, very low water-holding capacity, and low fertility.

Vegetation. The youngest dunes were observed at Asilomar State Beach, South Moss Beach, and Seventeen Mile Drive at Spanish Bay Golf Course. Youngest dunes support dune scrub habitat (Figure 7). The dune scrub is dominated by beach sagewort (*Artemisia*

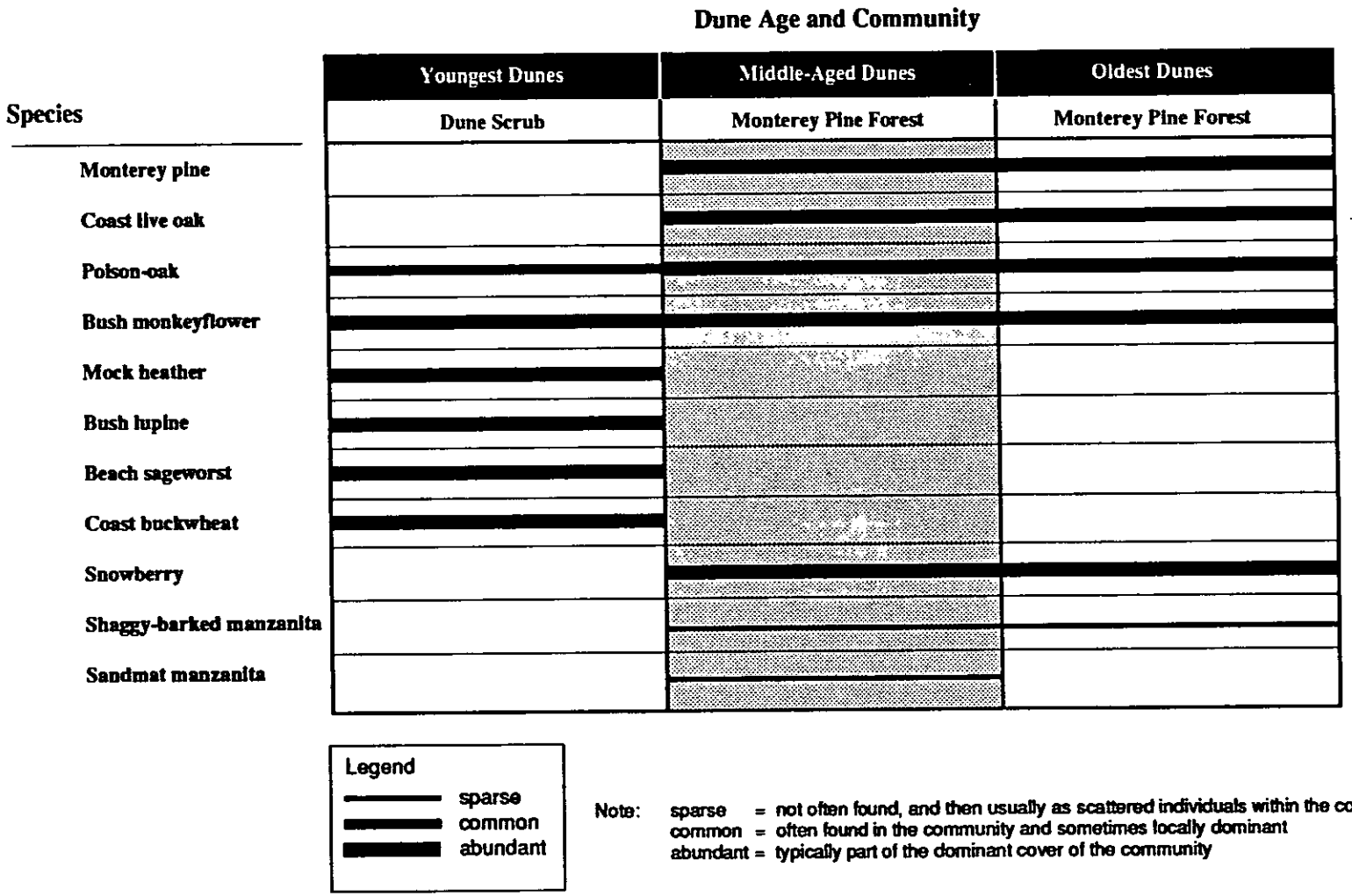

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Figure 7.
Distribution of Selected Trees and Shrubs in Mature Vegetation on Dunes

pycnocephala), mock heather (*Ericameria ericoides*), seacliff buckwheat (*Eriogonum parvifolium*), bush lupine (*Lupinus arboreus*), bush monkeyflower, and prostrate and erect forms of coyote brush. Old Monterey pine trees, twisted and scraggly from wind and salt, occasionally occur at the inland edge of dunes. It is not known if these established naturally; no natural regeneration was observed.

Middle-Aged Dunes

Soils. The middle-aged sand dunes occur inland of the youngest dunes and Terrace 1 and, in Carmel, inland of Terrace 2 as well. Areas along Congress Road and in Rip Van Winkle Open Space are the few remaining natural areas of significant size. The characteristic soil type is the Baywood series, an Entic Haploxeroll. The only pedogenic change is the accumulation of organic matter to a depth of 20 to 48 inches (Cook 1978). This results in increased water-holding capacity and increased fertility, allowing the establishment of Monterey pine. The range of soil pH, as affected by the pines, is medium acid.

Vegetation. Vegetation on middle-aged dunes was observed at Rip Van Winkle Open Space, along Congress Road, on Sloat Road near Seventeen Mile Drive, and on Seventeen Mile Drive at Spanish Bay Golf Course.

Middle-aged dunes support Monterey pine forest with a closed canopy at maturity (Table 3 and Figure 7). The Monterey pines achieve full height in multistoried stands. Pines up to 47 inches dbh were observed. Coast live oak is common and forms a subcanopy. The understory is rather open with much duff and grass along with low shrubs. The dominant understory species are poison-oak, bracken fern, California blackberry, and snowberry. Scattered individuals of shaggy-barked manzanita are present, especially in light gaps. Few pine seedlings are present, possibly because of deep shade or a thick duff layer. Pine saplings occur in light gaps. California blackberry and Bermuda buttercup are common on sites with a cover of mostly duff; these sites are possibly disturbed by foot traffic. A few small individuals of sandmat manzanita were found on the middle-aged dunes in Monterey pine forest. It is interesting to note that largest populations of sandmat manzanita occur on Baywood sands at Fort Ord (Jones & Stokes Associates 1992).

Near the interface with the youngest dunes, the Monterey pine forest on the middle-aged dunes supports scattered oaks, a grassy understory, and some dune scrub species such as bush lupine. California coffeeberry is also present.

Oldest Dunes

Soils. The oldest dunes occur generally further inland of the middle-aged dunes, except in the Asilomar area where there is a transition from the youngest to the oldest dunes, and in the Monterey Peninsula Country Club Shore Golf Course where there is a

Table 3. Understory and Overstory Characteristics of Monterey Pine Forest Subtypes on Pleistocene Dunes

Dune System Community[a]	Understory		Overstory		Monterey Pine	
	Dominants	Shrub Cover	Dominants	Canopy Closure	Height	Regeneration
Middle-aged dunes						
MPF	Poison-oak; mixed soft-leaved shrubs; grass; duff	Moderate	Monterey pine-oak	Closed	Full	Poor to Fair
Oldest dunes						
MPF	Grass; poison-oak; mixed soft-leaved shrubs	Low	Monterey pine-oak	Open to closed	Full	Poor to good

[a] Community classifications:

MPF = Monterey pine forest.

transition from Terrace 1 to the oldest dunes. Only very small, isolated areas remain in a semi-natural condition; perhaps the best remaining is at Asilomar.

Four dune soil types, Oceano, Elkhorn, Tangair, and Arnold, occur on the oldest dunes (Cook 1978). The Oceano series is classified as an Argic Xeropsamment, although it is more accurately an Ultic Haploxeroll. Soil characteristics include, in addition to organic matter accumulation, the eluviation of clay and subsoil accumulation as lamellae or thin bands. In addition, below the horizon of clay accumulation is a noncemented horizon of iron accumulation. The Elkhorn series is a Pachic Argixeroll and is further developed than the Oceano series with respect to both surface organic matter accumulation and subsoil clay accumulation. The Tangair series is an Aquic Durorthidic Xeropsamment, with an albic horizon, redoximorphic features including mottles and durinodes, and a subsoil horizon of iron accumulation, possibly even a spodic horizon. The Arnold series is a Durorthidic Xeropsamment with durinodes but no other redoximorphic features, possibly some albic horizons, some clay lamellae, and subsoils of cemented iron accumulation that may be spodic horizons (the distinctive appearance of the latter is referred to as the Aromas red sands or the Aromas Formation - it is evident in a cliff face in the city of Carmel). The Arnold series is undoubtedly a paleosol, a relict soil formed in a paleoclimate.

Of the above four soil series, the Tangair is the most widespread on the oldest dunes in the Monterey pine area. The other three are of limited extent. All could have and probably did support Monterey pine forests under historic natural conditions.

Vegetation. Vegetation on oldest dunes was observed on Seventeen Mile Drive near Sunset Drive and the Asilomar Conference Center. Few sites with natural vegetation remain on the oldest dunes and this vegetation is mostly disturbed. Natural vegetation on oldest dunes was determined based on observations of remnant patches and the experience of local experts (Moss pers. comm.).

The oldest dunes support Monterey pine forest (Table 3 and Figure 7). Pines up to 36 inches dbh were measured. The pine forest is multistoried. Coast live oak is present. The understory is open and grassy along with areas of sparse shrub cover. The understory is dominated by annual grasses such as ripgut brome. Dominant understory species are poison-oak, bracken fern, snowberry, and California blackberry. Common species on the oldest dunes include blue wildrye, giant wildrye, lizard tail, dune sedge (*Carex pansa*), and hedge nettle. The duff layer is thick. Monterey pine seedlings are sparse.

Inland Geomorphic Surfaces

Monterey pine forests extend a considerable distance inland from the coast and well inland of the marine terrace and dune sequence described above. The two principal geologic bedrock types are granite and granodiorite bedrock and shale bedrock. Shale bedrock begins around the summit of Huckleberry Hill and extends eastward to Jacks Peak and beyond. The granitic bedrock underlies the Monterey Peninsula west of Huckleberry

Hill, outcrops on intervening terrace slopes and some terraces, and extends eastward of Point Lobos and south of the Carmel River.

Shale Bedrock

Soils. The principal Monterey pine soil on shale bedrock is the Santa Lucia series, a Pachic Ultic Haploxeroll. Soil characteristics include a thick, dark mollic epipedon of organic matter accumulation; strongly acid soil pH; fine texture; good soil structure; moderate fertility and water-holding capacity; and 20- to 40-inch depth to fractured, rootable bedrock. Altogether this is a far friendlier plant soil than the soils of the marine terraces and dune sequence. An associated soil is the Reliz series, a Lithic Xeorthent, that supports a chaparral vegetation community. The Reliz series, in comparison, is shallow to bedrock (10-20 inches deep), has no mollic epipedon, poor soil structure, low fertility, and low water-holding capacity (Cook 1978).

Vegetation. Vegetation on the inland shale formation was observed along Aguajito, Loma Alta, and Jacks Peak Roads and at Jacks Peak Regional Park. Vegetative communities on inland shale formation are Monterey pine forest, chaparral, central (Lucian) coastal scrub, coast live oak woodland, and grassland.

The Monterey pine forest supports full-sized Monterey pines about 80-100' tall (Table 4). Coast live oaks, about 30-50 feet tall, form a subcanopy. At some sites, blue blossom and toyon grow to about 10-20 feet tall and form another vegetative stratum. The understory is an open grass cover with some sites dominated by low shrubs. Dominant shrubs are poison-oak, bush monkeyflower, California blackberry, coyote brush, and California coffeeberry.

Where Monterey pine forest intergrades with maritime chaparral, shaggy-barked manzanita is a dominant understory species. Where Monterey pine forest intergrades with coastal scrub, black sage, California sagebrush, and coyote brush are dominant in the understory.

Maritime chaparral occurs on the shale formation on hilltops where soils are shallow. Coastal scrub, dominated by California sagebrush, black sage, and coyote brush occurs on the shallow soils of steep slopes.

Inland of Jacks Peak Regional Park, Monterey pine forest intergrades with oak woodland and grassland.

Granitic Bedrock

Soils. The principal soil supporting Monterey pine forest on granitic bedrock is the Sheridan series described previously. Its soil characteristics are very similar to the Santa Lucia series. Analogous to the vegetation shift to a chaparral community on shale bedrock,

Table 4. Understory and Overstory Characteristics of Monterey Pine Forest Subtypes on Inland Bedrocks and Drainages

Geomorphic Surface Community[a]	Understory		Overstory		Monterey Pine	
	Dominants	Shrub Cover	Dominants	Canopy Closure	Height	Regeneration
Inland shale bedrock						
MPF	Grass; poison-oak; bush monkeyflower; mixed shrubs	Low to moderate	Monterey pine-oak or Monterey pine	Open to closed	Full	Good
Inland granitic bedrock						
MPF	Mixed shrubs, hard-leaved and soft-leaved	High	Monterey pine	Open to closed	Full	?
Drainages through coastal terraces and dunes						
MPRF	Mixed shrubs, high diversity	High	Monterey pine-oak	Closed	Full	Good
Drainages through inland shale and granite						
CRMPRF	Mixed shrubs, high diversity	High	Coast redwood-Monterey pine	Closed	Full	Good

[a] Community classifications:

MPF = Monterey pine forest.
MPRF = Monterey pine riparian forest.
CRMPRF = Coast redwood-Monterey pine riparian forest.

the associated Cieneba soil series on granitic bedrock is also a Lithic Xerorthent and has very similar soil properties to the Reliz series.

Vegetation. Vegetation was observed on the inland granitic bedrock at the eastern edge of Lobos Ranch on the slopes of Huckleberry Hill. The vegetation of inland granite bedrock includes Monterey pine forest and maritime chaparral.

The Monterey pine forest is well developed and multistoried (Table 4). Pines are full sized. The understory includes sites with a rather even mix of huckleberry, coyote brush, California coffeeberry, shaggy-barked manzanita, and poison-oak and sites dominated by one or a few of theses species. Other common shrubs include bush monkeyflower, broom, blue blossom, and toyon. Coast live oak is present.

The maritime chaparral occurs on inland granites on hilltops where soils are shallow. This chaparral has a high species diversity. Dominant species are shaggy-barked manzanita, Hooker's manzanita, and chinkapin. Other common species are silk tassel (*Garrya elliptica*), coyote brush, small-leaved lomatium, California aster (*Lessingia filaginifolia* var. *filaginifolia*), salal, chamise, Indian warrior (*Pedicularis densiflora*), bush monkeyflower, California coffeeberry, blue blossom, and bracken fern. Scattered Monterey pine are present in the chaparral in stunted form.

Drainages

Drainages through Coastal Terraces and Dunes

Soils. The typical soil series of the canyon riparian areas separating the marine terraces and dune segments is the Elder series, a Cumulic Haploxeroll. Related soil series are the Gorgonio and Arroyo Seco, both Fluventic Haploxerolls. All are sandy alluvium characterized by irregular accumulations of organic matter in the soil profile as a result of flood deposition.

Two roadcuts profile the soil transition from the pygmy forests on Terrace 5 to the riparian forests in drainages. A soil transect from pygmy forest to Monterey pine riparian forest at the S.F.B. Morse Botanical Reserve shows a Narlon transition of increasing depth to claypan and redoximorphic features and increasing thickness of A and O horizons, until the claypan and redoximorphic features drop out altogether in the transition to the Elder series. A soil transect from Terrace 5 pygmy forest to redwood-Monterey pine riparian forest along Gibson Creek transitions from Narlon to Huckleberry to Sunridge to Sheridan to Elder.

Vegetation. Vegetation was observed in drainages cutting through the middle-aged and oldest dunes at Rip Van Winkle Park; Terraces 3 and 4 on Forest Lake Road; Terraces 3, 4, and 5 at the S.F.B. Morse Reserve; and Terrace 5 at Lobos Ranch.

Drainages on the Monterey Peninsula and Point Lobos support Monterey pine forest on the side slopes and channel bottoms (Table 4). Monterey pine grow to full size. The understory is usually a more diverse assemblage than on adjacent terraces. Coast live oak is usually present, even in drainages through terraces that do not support coast live oak, such as Terrace 5 pygmy forest. The understory is dense and includes species such as poison-oak, California blackberry, California coffeberry, California wax-myrtle (*Myrica californica*), California rose (*Rosa californica*), toyon, huckleberry, bracken fern, swordfern (*Polystichum munitum*), nightshade (*Solanum* sp.), pampas grass, poison-hemlock (*Conium maculatum*), salal, sedge (*Carex* sp.), and broom. California blackberry is often the dominant species in channel bottoms.

Some drainages that cut through Terrace 5 support redwood-Monterey pine riparian forest. See the description below under "Drainages through Inland Geologic Formations".

Drainages through Inland Geologic Formations

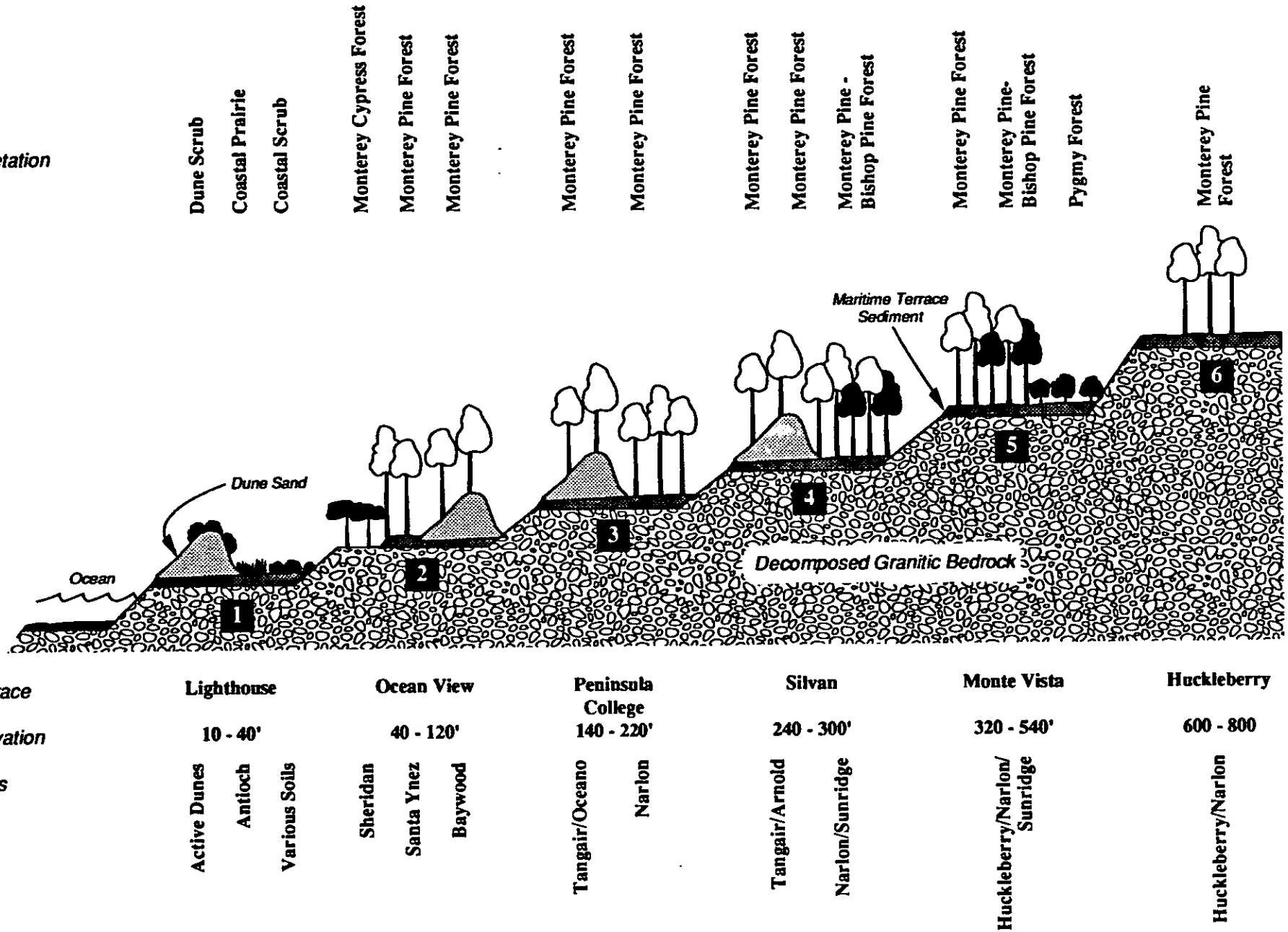
Soils. Soils of drainages that cut through inland granite and shale bedrock include Elder, Gorgonio, and Arroyo Seco.

Vegetation. Vegetation was observed in drainages cutting through inland granite at Lobos Ranch.

Gibson Creek on Lobos Ranch supports coast redwood-Monterey pine riparian forest (Table 4). This drainage cuts through inland granitic formation and Terrace 5. Coast redwood (*Sequoia sempervirens*) occurs on lower slopes and in the streambed. Monterey pine occurs on the slopes above the stream channel. Scouler's willow is present. The understory includes California blackberry, chaparral current, broom, huckleberry, swordfern, poison-oak, blue blossom, and thimbleberry (*Rubus parviflorus*).

DISCUSSION OF FINDINGS

Monterey pine occurs on a variety of soil types within the pedogenically complex region of the Monterey Peninsula, Point Lobos, and adjacent areas inland. Specific soil-vegetation associations have been demonstrated for diverse Monterey pine vegetation communities and variant Monterey pine growth forms. A specially significant soil-vegetation association is the occurrence of Monterey pine as a primary species on a six-step marine terrace ecological staircase and soil chronosequence (Figure 8). Monterey pine enters on the second marine terrace, avoiding conditions of saline-sodic soil and salt-spray in proximity to the shoreline on Terrace 1. Soil environmental conditions on the upper marine terraces are extremely challenging to plant growth, including Monterey pine. Soil profile characteristics are indicative of hydric soil conditions and soil leaching occurring for geologically long periods of time. Under the present climatic regime, seasonally saturated soil conditions alternate in an annual cycle with seasonally dry soil conditions with an



Jones & Stokes Associates, Inc.

Figure 8
The Monterey Ecological Staircase

extremely low soil water-holding capacity. Shallow depths to claypan and hardpan severely limit rooting depths. Soil chemistry ranges to extremely acid conditions of aluminum toxicity, very low fertility, and deficiency of essential plant nutrients. Under the most extreme conditions in the continuum of soil characteristics, Monterey pine drops out in the transition to pygmy forest.

Monterey pine also occurs on a chronosequence of sand dune soils, dominating the vegetation on stabilized Pleistocene dunes (middle-aged and oldest dunes), where sufficient accumulation of organic matter has occurred in sand dune soil pedogenesis (Figure 8). The youngest, active dunes of the Holocene do not support Monterey pine. The middle-aged and oldest dunes on the Monterey Peninsula support Monterey pine forest. In contrast, Baywood sands of the middle-aged dunes at Fort Ord support maritime chaparral, and Oceano soils of the oldest dunes at Fort Ord support a scrubby form of oak woodland and annual grasslands (Jones & Stokes Associates 1992). Arnold soils of the small remnant of Aromas Formation at Carmel apparently support Monterey pine forest, but the extensive areas of Arnold soils at Fort Ord support maritime chaparral (Jones & Stokes Associates 1992). Differences between the stabilized dune vegetation at the Monterey Peninsula and Fort Ord are interesting. These differences do not appear to be determined by soils and may be the result of differences in microclimate, such as the amount of precipitation and frequency of summer fog. Fort Ord does not have the abrupt coastal relief of the Monterey Peninsula and therefore the dune systems on the peninsula may support a moister microclimate.

Inland areas within the summer fog zone, support Monterey pine communities on upland soil types of moderate acidity and fertility, without the extreme pedogenic conditions of the upper marine terraces. Monterey pine continues inland on upland soil types in increasingly limited microtopographical and microclimatic locations until discontinuing altogether. The explanation of this distribution pattern for Monterey pine as the result of decreasing available moisture in inland areas is a reasonable conclusion.

Monterey Pine Forest Subtypes

Subtypes of Monterey pine forest were described based on canopy and understory composition and structure (Tables 1-4).

Middle-aged dunes, Terrace 2, slopes between Terraces 1 and 2, and slopes between Terraces 2 and 3 support full-sized Monterey pine with a low carpet of soft-leaved shrubs (dominated by poison-oak and bush monkeyflower) in the understory (Tables 1-3). Regeneration of Monterey pine on the dunes appears to be less than on Terrace 2 and the slopes between terraces. Low regeneration could be the result of the dense growth of European annual grasses every spring that smothers the pine seedlings (Moss pers. comm.).

The oldest dunes and Terrace 3 support full-sized Monterey pine in more open stands with a grassy understory and scattered patches of soft-leaved shrubs (Tables 1 and 3). Monterey pine regeneration appears to be less on the oldest dunes than on Terrace 3.

The slopes between Terraces 3 and 4, Terraces 4 and 5, and Terraces 5 and 6 support full-sized Monterey pine typically with an understory of manzanita and huckleberry (Tables 1-2). The slopes between Terraces 5 and 6 also support Bishop pine forest.

Terrace 4 is the first terrace where Monterey pine become stunted in height, Bishop pine appear as forest associates in some stands, and hard-leaved shrubs (shaggy-barked manzanita and huckleberry) are dominant in the understory. Monterey pine forest was subdivided into three types on Terrace 4: Monterey pine forest with a dense understory of manzanita and huckleberry; Monterey pine forest with an understory of grass and scattered, dense patches of manzanita; and mixed Monterey pine-Bishop pine forest with a manzanita and mixed shrub understory (Table 1).

Terrace 5 supports two Monterey pine forest subtypes, Monterey pine forest and Monterey pine-Bishop pine forest, and pygmy forest where Monterey pine is sparsely distributed (Table 1). Monterey pines in all forests on Terrace 5 are stunted in height, and in pygmy forest they are severely stunted. Hard-leaved shrubs dominate the understory and many new shrub species appear on Terrace 5, including rare species such as Hooker's manzanita, sandmat manzanita, and Monterey ceanothus.

Some characteristic features of the Monterey pine forest on Terrace 6 are an understory dominated by huckleberry and shaggy-barked manzanita, Monterey pine are stunted in height, occurrences of coast live oak are uncommon to very sparse, and madrone and Scouler's willow occur as scattered individuals (Table 1).

Drainages through coastal terraces and dunes support Monterey pine riparian forest (Table 4). The understory is a diverse assemblage of shrubs. Drainages through inland bedrock formations support coast redwood-Monterey pine riparian forest with a high-diversity shrub understory (Table 4).

Inland shale formation supports Monterey pine forest in tall, multistoried stands (Table 4). The understory varies depending on slope, aspect, and soils, but mainly consists of grass with patches of soft-leaved shrubs, such as bush monkeyflower and poison-oak. Monterey pine forests on inland granitic formation support a different understory than forests on shale; hard-leaved and soft-leaved shrubs are present, often in dense cover, and grass cover is less important (Table 4).

Successional Patterns

Secondary succession following fire was observed in Monterey pine forest on Terrace 2, Terrace 6, slopes between Terraces 1 and 2, and slopes between Terraces 5 and

6. In all cases, Monterey pine appears to reestablish rapidly on the site along with the same shrubs that will dominate the understory vegetation of mature forest on the geomorphic surface and soil type. A greater diversity of shrubs and herbs are present in the early successional stages. These species are displaced as the forest matures and are not found in late successional stages. Many of the early successional species are dependent on fire-caused and other openings to maintain substantial population sizes.

The same pattern of succession was observed in pygmy forest on Terrace 5. Diversity decreases as the Bishop pine, Gowan cypress, shaggy-barked manzanita, and huckleberry mature and outcompete other species for space and light.

Comparison of the Mendocino and Monterey Ecological Staircases

The famous Mendocino ecological staircase was recognized and described by Hans Jenny and others 25 years ago (Jenny et al. 1969), although the unusual soil-vegetation relationships had been recognized a number of years earlier (Gardner and Bradshaw 1954). Now, a second ecological staircase has been recognized on the Monterey Peninsula and Point Lobos (Figure 8). Although presently separated by a distance of 300 miles (the Monterey Peninsula on the Pacific Plate is moving north toward the Mendocino coast on the North American Plate), with a different underlying geology and climate, the parallels between the two are remarkable.

First is the number and elevations of the terraces. The Mendocino staircase is generally recognized as having five terraces and the Monterey staircase has six terraces. The elevations of the Mendocino Terraces 1 through 5 fall within the elevation ranges of Monterey Terraces 2 through 6, respectively (Table 5). The equivalent to Monterey Terrace 1 appears to be absent in Mendocino; this terrace may have been lost to erosion because of the more rapid erodibility of the underlying sandstone bedrock in Mendocino versus the granitic bedrock of Monterey. Terrace 1 in Monterey is itself substantially eroded and narrow in width with respect to the upper terraces. At Point Arena, there is evidence of a first terrace, equivalent to Monterey Terrace 1, for the Mendocino staircase at an elevation of about 60 feet. The strong correlation in the number and elevations of terraces implies that similar or related tectonic forces have created the landscape in both locations. If the terraces at Monterey and Mendocino are of similar tectonic origin, then the respective soil-vegetation evolutionary timescales would also be similar.

A strong correlation in soil types exists between the two regions. Both contain separate soil chronosequences on dune sand and on marine terraces (Jenny et al. 1969). The same pedogenic processes, such as podzolization, lessivage, gleization, and laterization, that formed the sequences occur on both terraces. The Aborigine series (Typic Albaquult) of the Mendocino staircase is the same taxonomy as the Narlon series. The Ferncreek series (Plinthic Palehumult) is the same in taxonomy and very similar in profile to the Huckleberry series. The famed Blacklock series hardpan soil has a Monterey counterpart in the Sunridge series, although the two soils may not be strictly analogous. The Casper and

Table 5. Comparison of Terrace Elevations between the Monterey and Mendocino Staircases

Monterey		Mendocino[a]	
Terrace Level	Elevation (in feet)	Elevation (in feet)	Terrace Level
Terrace 1	10-40	--	
Terrace 2	40-120	100	Terrace 1
Terrace 3	140-220	175	Terrace 2
Terrace 4	240-300	300	Terrace 3
Terrace 5	320-540	425	Terrace 4
Terrace 6	600-800	650	Terrace 5

[a] Source: Jenny et al. 1969.

Noyo series on Mendocino sand dunes have morphological profile features similar to the Oceano, Tangair, and Arnold series of Monterey.
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Soil biogeochemical characteristics are also remarkably similar. The range in pH from medium acid to extremely acid is found in both staircases, and at analogous locations in the chronosequences (Jenny et al. 1969). Parallel ranges in organic matter, fertility, mineralogy (including plinthite), and hydric characteristics (mottles to large concretions) are also found. Somewhat wetter soil conditions occur at Mendocino at present, due to the substantially greater rainfall.

The parallel in soil characteristics is mirrored by the parallel in vegetation. Pygmy forest occurs in both ecological staircases, although it occurs on Terraces 3-5 at Mendocino (equivalent to Terraces 4-6 at Monterey) and only on Terrace 5 at Monterey. The occurrence of pygmy forest on lower terraces at Mendocino compared to Monterey is not surprising, considering the wetter climate at Mendocino would be expected to enhance the rate of pedogenesis. Many of the same plant species occur in the pygmy forests at both locations, including Bishop pine, huckleberry, toyon, salal, and bear grass (*Xeropyllum tenax*). Pygmy cypress (*Cupressus goveniana* ssp. *pigmea*) of the Mendocino pygmy forests is considered a conspecific with Gowan cypress of Monterey pygmy forests (Hickman 1993). The Mendocino pygmy forest supports two species of manzanita's, Fort Bragg manzanita (*Arctostaphylos nummularia*) and hairy manzanita (*Arctostaphylos columbiana*), that occupy similar niches as shaggy-barked manzanita and Hooker's manzanita in Monterey. Bolander pine (*Pinus contorta* ssp. *bolanderi*) occurs in pygmy forests at Mendocino, but not at Monterey.

The forests of the lower terraces and stabilized dunes of Mendocino support coast redwood, Douglas fir (*Pseudotsuga menziesii*), Bishop pine, and shore pine (*Pinus contorta* ssp. *contorta*). Monterey pine occupies the equivalent dominant forest tree niche on terraces and stabilized dunes at Monterey. The drier climate at Monterey probably is the reason that redwood and Douglas fir are not found in these low elevation coastal areas, especially on soils without root-restricting claypans and hardpans, such as the stabilized dunes and intervening slopes between marine terraces. Bishop pine forests of full-sized trees occur at both Monterey and Mendocino.

The inland granitic bedrock formation at Monterey supports redwood-Douglas fir forest in the Santa Lucia Mountains similar to the redwood-Douglas fir forest of the inland sandstone bedrock formation at Mendocino.

Staircase on Shale Bedrock

The Monterey ecological staircase described in this report formed on the granite substrate of the Monterey Peninsula and Point Lobos. The staircase of marine terraces has also formed on shale substrate at Monterey Peninsula College, U.S. Naval Post Graduate School, Del Monte Golf Course, and adjacent areas (Figures 3 and 4). These terraces also support

Monterey pine forest, but the pattern vegetation and soils on them has not been characterized as little undisturbed land remains.

RECOMMENDATIONS FOR CONSERVATION

The results of this study indicate that Monterey pine forest cannot be treated as a indivisible entity. Strong and subtle differences can be found between the Monterey pine forests growing on different geomorphic surfaces and soils. Historical losses of Monterey pine forest have not been evenly distributed across these forest subtypes. Little natural forest remains on Terrace 3, Terrace 4 on granite substrate, Terrace 6, and oldest dunes. Many forests on intervening slopes between terraces have been preserved because they are on slopes and not suitable for development. Most of the historical forests on inland shale and granite bedrock remain. Continued development pressures threaten forests on all geomorphic surfaces, but forests on each geomorphic surface must be considered independently. A goal of preserving representative stands of functional forest on each geomorphic surface would best protect the full range of Monterey pine forest diversity. Rare and endemic species are not evenly distributed among the subtypes of Monterey pine forest (California Department of Fish and Game 1994). The distribution of populations of these species and the distribution of additional suitable habitat for them should be considered in conservation planning for Monterey pine forest.

Although allozyme studies of enzyme systems have indicated that within-stand genetic variation is greater than among-stand variation in Monterey pine, no study has focused on the possible genotypic differences between pines on different geomorphic surfaces (Moran et al. 1988, Plessas and Straus 1986). The extreme soil conditions that result in stunted Monterey pine on Terraces 4, 5, and 6 could result in strong selection for particular genotypes. Preserving stands of Monterey pine on the widest variety of geomorphic surfaces and soils is a conservative means for preserving the range of Monterey pine genetic diversity and natural selection regimes to act on that genetic variation. The elucidation of the patterns of Monterey pine, geomorphic surfaces, and soils presented in this report should assist in the formulation of new experiments for the study of Monterey pine population genetics and ecology.

LIST OF PREPARERS

Principal-in-Charge

Daniel Airola

Project Manager/Plant Ecologist

Paul Cylinder

Soil Scientist

Wayne Verrill

Botanist

Susan Bushnell

Forester

Nick Dennis

Librarian

Rubby Hampton

Geographic Information System Specialists

Chris DiDio
Ann Sever
Gerrit Platenkamp

Graphic Artists

Christy Anderson
Tony Rypich

Editor

Cynthia Casanova

Word Processing Operator

Fern Weston
David Haining

CITATIONS

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Personal Communications

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